USDA Animal and Plant Health Inspection Service
U.S. DEPARTMENT OF AGRICULTURE

Wildlife Services

Innovative Solutions to Human-Wildlife Conflicts

National Wildlife Research Center Accomplishments, 2020

United States Department of Agriculture
Animal and Plant Health Inspection Service
Wildlife Services

The mission of Wildlife Services' (WS) National Wildlife Research Center (NWRC) is to apply scientific expertise to resolve human-wildlife conflicts while maintaining the quality of the environment shared with wildlife. NWRC develops methods and information to address human-wildlife conflicts related to the following:

- agriculture (crops, livestock, aquaculture, and timber)
- human health and safety (wildlife disease, aviation)
- property damage
- invasive species
- threatened and endangered species

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Invasive species can negatively impact native plants and animals on islands, affecting biodiversity. NWRC works with a variety of partners to mitigate those impacts. Laysan Albatross (Diomedea immutabilis) adult with chick, Midway Atoll, NW Hawaiian Island. *Photo: Adobe Stock*

Message From the Director

In April 2020, I accepted the position of Director for the Wildlife Services National Wildlife Research Center (NWRC). I am honored to be a part of this innovative research and development team. I look forward to helping employees continue the Center's strong tradition of excellence in wildlife damage research.

I never anticipated my first and most important task as Director would be to guide our employees through an uncertain and unprecedented time. The COVID-19 pandemic touched every one of us, both personally and professionally. In true Wildlife Services fashion though, our employees rose to the challenge and found new ways to keep meeting our mission and provide wildlife damage management assistance to those in need. NWRC scientists continued to produce high-quality information, publishing 105 peer-reviewed manuscripts and 18 trade publications or book chapters in 2020. We also had a record number of publication downloads—more than 172,000, an increase of nearly 30 percent over the previous 4-year average of 133,000. Instead of meeting in person, we held and attended conference calls, and virtual meetings and conferences. It certainly was and still is an adjustment. But one positive is that meeting and conference attendance soared as employees and collaborators became more at ease with the various virtual conferencing platforms.

The high-quality research and innovation of NWRC scientists never fail to impress me. But our staff's work throughout 2020 exceeded my highest expectations. This year's report is an outstanding compilation of these collaborations and achievements despite the pandemic and ever-changing work conditions.

Jason Suckow with Alaskan muskox
Photo: USDA, Wildlife Services

I have no doubt NWRC will continue to face unique challenges in 2021. Perseverance, creativity, and a "can do" attitude—qualities shown by so many in 2020—will ensure that the NWRC continues to serve our customers and fulfill our mission. This gives me great comfort. As one of my high school coaches once said, "We will not let the challenges we face define us. We will be defined by how we overcome those challenges."

It is with pleasure that I present to you the 2020 research accomplishments for the National Wildlife Research Center.

Jason Suckow
Director
National Wildlife Research Center
Wildlife Services, APHIS-USDA
Fort Collins, CO

Contents

Though the COVID-19 pandemic provided new challenges, WS employees continued to address wildlife damage issues throughout 2020. On Guam, biologists work to develop new tools and methods to manage invasive brown treesnakes. *Photo: USDA*

Innovative Solutions to Human-Wildlife Conflicts

National Wildlife Research Center Accomplishments, 2020

Research Spotlights

Caribbean island
Photo: Adobe Stock

Invasive species are linked to 86 percent of all recorded plant and animal extinctions on islands.

The National Wildlife Research Center (NWRC) is part of Wildlife Services (WS), a program within the U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS). Our researchers are dedicated to finding biologically sound, practical, and effective solutions for resolving wildlife damage management issues. The following spotlights feature some of WS NWRC's expertise and our holistic approach to addressing today's wildlife-related challenges.

SPOTLIGHT: Restoring Island Biodiversity

Invasive species can have profound and transformative effects on native plants, animals, and ecosystems. This is especially true on islands, where native species have evolved in relative isolation from predators. Invasive Norway rats (*Rattus norvegicus*), black rats (*Rattus rattus*), Polynesian rats (*Rattus exulans*), and house mice (*Mus musculus*) inhabit more than 80 percent of the world's major island groups and are likely responsible for most extinctions of native island species and accompanying ecosystem changes. Eradicating these and other invasive species from islands is essential for conserving and restoring island biodiversity.

WS has been actively involved in invasive species management on islands for many decades. In 2016, WS signed a Memorandum of Understanding with the U.S. Fish and Wildlife Service and Island Conservation "for the purpose of furthering wildlife conservation and ecosystem management interests and responsibilities for the islands, atolls, and reefs under the jurisdiction of the United States," building upon years of collaboration. WS also collaborates with the U.S. Department of Defense, U.S. Department of the Interior, State agencies, and other organizations to address invasive species impacts and biosecurity issues related to islands. WS aids in designing, implementing, and evaluating wildlife damage management activities on islands; coordinates and provides guidance on the legal use and registration of vertebrate control methods; and helps protect reintroduced or recovering native species. The following sections highlight NWRC's work to support these activities.

Establishing the WS Island Restoration Committee

In 2019, WS created the Island Restoration Committee (IRC) to provide leadership, guidance, and technical assistance to employees and partners in managing, controlling, and mitigating invasive and introduced vertebrate species for island restoration projects.

Invasive black rats (pictured), Norway rats, Polynesian rats, and house mice occur on more than 80 percent of the world's major island groups and are likely responsible for most extinctions of native island species and accompanying ecosystem changes.
Photo: U.S. Department of Defense, Scott Vogt

"The IRC is made up of both research and operations experts who are especially knowledgeable on invasive species and island biodiversity issues," notes Emily Ruell, NWRC registration specialist and IRC Chair. "Much of our work focuses on bringing together the right people and tools to aid wildlife damage management and research on islands. Wildlife species of interest include invasive or introduced rats, mice, mongooses, snakes, lizards, and birds, as well as feral dogs, cats, goats, pigs, and chickens."

In 2020, the IRC supported island rodent eradication planning efforts for Midway Atoll, Wake Atoll, Amchitka and Great Sitkin Islands in the Aleutians, and Savana Island. The IRC also supported research and development of new products such as bait matrices and bait delivery mechanisms for island invasive vertebrate species.

Working with WS' Pesticide Coordination Subcommittee, the IRC negotiated and finalized label amendments with the U.S. Environmental Protection Agency (EPA) for three APHIS-registered island conservation rodenticides (Diphacinone-50 Conservation, Brodifacoum-25D Conservation, and Brodifacoum-25W Conservation) to make them available for purchase by all Federal agencies and more adaptable to island-specific conditions. The IRC also proposed new island conservation registrations to the EPA for two commercially available rodent baits, and a third is in development. These new registrations will provide additional control options for invasive rodents on islands and on abandoned or grounded vessels that harbor rodents.

California kingsnakes are an invasive species in Spain. NWRC is exploring if current tools for controlling other invasive snakes could be used on California kingsnakes in areas where they are invasive and impacting native wildlife.
Photo: Adobe Stock

Developing New Baits

The WS IRC, WS Pesticide Coordination Subcommittee, and WS NWRC Registration Unit work together to register new chemical agents and pesticides with the EPA for use in wildlife damage management, including invasive species management. This also involves modifying or expanding registration labels for use with new applications or species.

For example, dead neonatal mice treated with 80-milligram (mg) acetaminophen tablets are approved as a registered pesticide to control invasive brown tree snakes (*Boiga irregularis*) on Guam and could be used as an oral toxicant to control invasive California kingsnakes (*Lampropeltis californiae*).

"California kingsnakes are an invasive species on Gran Canaria, Canary Islands, and Spain and are threatening the island's native wildlife, including the Gran Canaria skink and Gran Canaria giant lizard," says NWRC research wildlife biologist Dr. Shane Siers. "Given our success with registered acetaminophen tablets on invasive brown tree snakes, we wanted to see if the chemical agent might also be effective on California kingsnakes."

In studies with captive snakes, NWRC and Truman State University researchers evaluated the oral toxicity of acetaminophen and determined the dosage needed for lethal control of invasive California kingsnakes. Treatments of 60 mg and 80 mg had 100 percent mortality, with death occurring approximately 38 hours after the consumption of a treated dead mouse.

Even though the study showed that dead mouse baits treated with acetaminophen may be an effective control method on Gran Canaria, researchers caution this should not be the only method used to protect native species or eradicate California kingsnakes on the island. Future efforts should involve an integrated approach and focus on preventing California kingsnakes from invading other Canary Islands.

In Hawaii, WS is working with its partners to identify new baits for use with invasive mongooses. The small Indian mongoose (*Urva auropunctata*) was originally released on several tropical islands in the Pacific to help control invasive rats and mice but is now seen as a pest that impacts native birds, reptiles, amphibians, insects, fruits, and plants. On some islands in the Caribbean, mongooses also carry and transmit the rabies virus. In Hawaii, there are ongoing mongoose control efforts on the islands of Oahu, Maui, Hawaii, and Molokai.

The NWRC Hawaii field station is partnering with the Hawaii Invasive Species Committee (HISC) to develop a new toxic bait for invasive mongooses. Diphacinone is highly toxic to mongooses and is currently registered in Hawaii as a mongoose control agent. However, the only registered diphacinone formulation has a bait matrix composed of cereal grain and wax, which is not attractive to mongooses.

NWRC and HISC have conducted laboratory trials with captive mongooses to evaluate potential baits. Studies have shown the fish-based bait matrix of a pesticide product (FOXSHIELD) used to control invasive foxes in Australia is highly palatable to mongooses. Because of this and other desirable characteristics related to its use and manufacturing, the bait matrix in FOXSHIELD was selected

NWRC's Hawaii field station is conducting laboratory and field trials to help register a new toxicant bait matrix for invasive mongooses. Mongoose impact native birds, reptiles, amphibians, insects, fruits, and plants on several Pacific islands. In Puerto Rico, they also carry and transmit the rabies virus.

Photo: Adobe Stock

for a novel formulation with 0.005-percent diphacinone. NWRC and HISC are preparing for trials with captive mongooses to establish the efficacy of this novel toxicant formulation.

The toxicant bait is intended to be part of an integrated approach to help prevent the establishment of mongooses on islands, such as Kauai and Lanai, as well as to control established mongoose populations on other islands in the Pacific Basin, Florida, and Caribbean U.S. Territories (Puerto Rico, U.S. Virgin Islands) to protect native species and prevent disease, such as rabies.

Evaluating Management Tools and Strategies

Over the years, WS has helped design and carry out invasive species eradications on islands across the Western Hemisphere. More recently, WS assistance has expanded to include evaluating the impacts of eradication efforts on both target and nontarget species.

"Typically, rodent eradications involve broadcasting anticoagulant rodenticide bait across most, if not all, areas of an island," says Dr. Siers. "But broadcasting toxicants can put people and nontarget species in marine and terrestrial environments at risk of exposure."

In 2012, approximately 18,000 kilograms of 0.0025-percent brodifacoum bait was

Rodent eradications on islands typically involve broadcasting anticoagulant rodenticide bait across most, if not all, areas of the island. NWRC and its partners work to evaluate and reduce environmental risks associated with rodenticide use.
Photo: USDA, Are Berentsen

broadcast across Wake Atoll in the central Pacific Ocean to eliminate invasive rats and protect the island's native plants and animals. To better understand the long-term impacts of potential rodenticide exposure on the island's fish communities, NWRC and Colorado State University researchers collected whole-body live fish samples from six nearshore sites and one intermittently land-locked pond 3 years after the rodent eradication effort.

Of the 69 samples collected and tested, 2 individuals of black snapper (*Lutjanus fulvus*) contained levels of brodifacoum too low to be accurately quantified. Both fish were caught in the intermittently land-locked pond in an area of the island that received heavy brodifacoum baiting. Brodifacoum was not detected in any of the nearshore open marine sites.

These results show that, under some circumstances, very low levels of brodifacoum can occur in a low proportion of fish tissues for as long as 3 years after applying the rodenticide at levels unlikely to cause adverse environmental effects. Such information is valuable in assessing the relative environmental risks of rodenticide use in eradications to protect threatened species and restore island ecosystems.

In addition to evaluating impacts of management efforts on nontarget species, WS also helps evaluate the specificity and effectiveness of various management tools and strategies. NWRC researchers are collaborating with the Hawaii Department of Land and Natural Resources, Kauai Invasive Species Committee, and Texas A&M University-Kingsville to evaluate several management methods for the control of invasive rose-ringed parakeets (*Psittacula krameria*) in Hawaii.

Rose-ringed parakeets are an invasive species in the United States, with established populations in California, Florida, and Hawaii. They cause significant damage to natural resources and agriculture because of their generalist diet. Large flocks of rose-ringed parakeets also roost on and near human-made structures, resulting in public health and safety concerns from parakeet collisions with aircraft, disease transmission, feces accumulation, and noise complaints.

"In Hawaii, the spread of rose-ringed parakeets is not only a concern to agricultural producers, but also conservationists because they potentially impact native wildlife, spread invasive plant seeds, and destroy native plants," says Dr. Steven Hess, NWRC Hawaii field station leader and supervisory research biologist.

After many years of exhibiting a low population on Kauai, the species' population is rapidly increasing and causing a wide range of human-wildlife conflicts.

In 2020, a team of NWRC and Texas A&M University-Kingsville researchers began testing a variety of feeders for use in delivering population control agents, such as reproductive inhibitors or toxicants, to rose-ringed parakeets on Kauai.

Researchers pre-baited several sites with large, open-platform feeders and nontreated bait, with the aim of attracting multiple bird species to the study sites. Feeders were left in the field for 12 weeks and baited with commercial bird seed, whole peanuts, artificial fruit, and decoy parakeets. Motion-activated cameras showed the parakeets did not use the open-platform feeders, and thus the design was eliminated as a potential control method. A second round of field trials is evaluating the use of an elevated hopper feeder, which holds birdseed and dispenses it into a tray at the bottom of the hopper. Introduced rose-ringed parakeets are known to use these types of feeders in other habitats. If these trials are successful, design evaluations may continue with a parakeet-specific feeder that was originally developed by biologists at NWRC's Florida field station for use on invasive monk parakeets (*Myiopsitta monachus*). These parakeet-specific feeders were shown to effectively deliver treated bait to monk parakeets while reducing access to the bait by nontarget species.

Preventing Rodent Invasions

Understanding how rats behave when they first arrive in a new environment aids in developing effective tools and techniques to prevent rodent invasions.

"Rats have many characteristics that make them effective invaders," says NWRC research wildlife biologist Dr. Gary Witmer. "They can live in a variety of habitats, are small, secretive, and nocturnal, and have keen senses of touch, taste, and smell."

As invasive species, rats cause serious damage to native plants and animals, agriculture, property, human health, and other resources. On islands, where predators are often lacking, invasive rats can decimate native plant and seabird populations.

NWRC and Texas A&M University-Kingsville researchers are testing several bird feeder designs for use in delivering population control agents to invasive rose-ringed parakeets on Kauai.

Photo: Texas A&M University-Kingsville, Jane Anderson

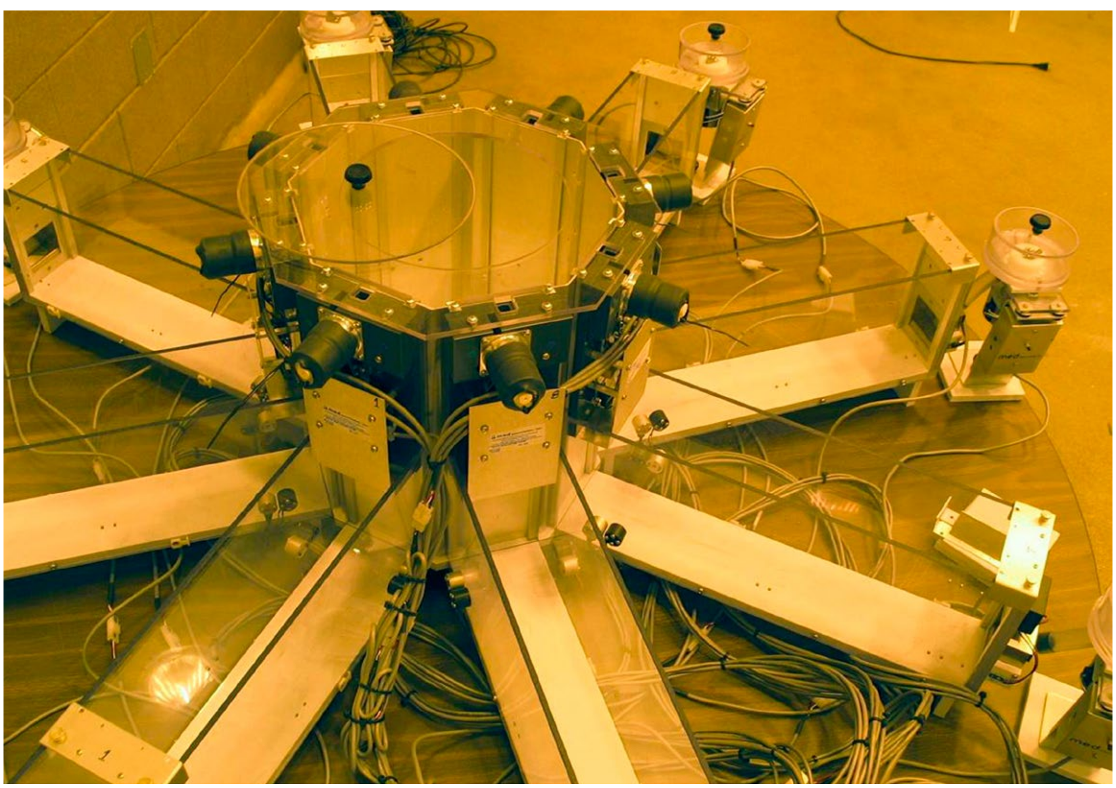
To develop better biosecurity methods for detecting and preventing rat invasions on islands, NWRC researchers conducted a series of laboratory experiments that simulated invasions by Norway rats, black rats, and Polynesian rats.

Wild-caught rats were placed into a radial maze with eight arms that represented a novel environment. Researchers monitored and compared the reactions of the rats to various odors and other attractants, such as food, shelter, water, and other rats. Although there were some differences in responses by species and sex, most rats sought out and spent considerable time in the radial arm that included a den box, suggesting an immediate need for security and shelter when in an unfamiliar setting. Rats also sought out feces of other rats, suggesting the need for social contact or reproduction. The rats, which had not been food deprived, did not seem interested in food sources, although there was some attraction to water sources.

Based on these findings, researchers surmise that a secure den box with certain food and rat odors might entice and hold invading rats in a restricted area for a short period. Such control methods could be useful in ports of entry or other locations where invading animals may first appear.

Developing Genetic Tools for the Future

While traditional removal methods such as toxicants have been successful in eradicating invasive species on islands, these approaches are costly and time-consuming. Their use can be limited due to concerns about secondary hazards to people, domestic animals, and nontarget species. Emerging tools, such as genome editing, hold promise for future invasive species management.



Wild-caught rats were placed into a radial maze with eight arms to monitor and compare their reactions to various odors and other attractants, such as food, shelter, water, and other rats. The maze simulates a novel environment and allows NWRC researchers to see how rats may behave when they first arrive to a new environment
Photo: USDA

Genome editing to produce engineered gene drives promotes the inheritance of a particular gene to increase its prevalence in a population. During normal sexual reproduction, each of the two versions of a given gene (also known as alleles) has a 50-percent chance of being inherited by offspring (Mendelian inheritance). Gene drives are genetic systems that circumvent these traditional rules. They greatly increase the odds that one specific version of a gene will be passed on to offspring. Thus, gene drives could be used to change a population into a single sex population or could promote a particular gene that causes the demise of a population. Gene drives occur naturally, but the idea of engineering them for disease and invasive species management emerged over the last several decades.

Gene drive technologies designed to eliminate a specific population provide an alternative approach for invasive species management, but the potential for drive-bearing individuals to escape from target release areas and impact populations elsewhere is a major concern for conservationists and managers.

As part of a multi-agency collaboration, NWRC geneticists investigated a novel gene drive approach ("locally fixed alleles") for potential use in managing invasive species populations.

"Basically, we are exploring whether certain isolated rodent populations, such as those on islands, exhibit enough genetic isolation from neighboring mainland populations that their specific alleles could be identified and targeted for gene drive constructs," says NWRC geneticist Dr. Toni Piaggio. "This targeted approach would make the gene drive population specific, thus restricting the unintended spread of a drive and any potentially negative impacts on neighboring mainland rodent populations."

The approach assumes that rodent populations on small islands experience genetic drift that leads to their alleles becoming "fixed" (i.e., identical). In contrast, rodents that exist in larger populations on the mainland maintain more diverse alleles.

North Carolina State University and NWRC researchers used mathematical models of island mouse populations to explore the feasibility of this approach and the degree to which localization can be achieved. Model simulations showed that if a mouse bearing a gene drive from a locally fixed allele were to escape to a neighboring mainland mouse population in which the target allele was not fixed but still present, the mainland mouse population would experience a small degree of population suppression. Eventually, the much larger and diverse mainland population would rebound from any impacts. The comparatively large size of the mainland mouse population with its diverse alleles would prevent the gene drive from spreading effectively.

Next Steps—NWRC researchers continue their work to help reduce damage by invasive species and restore island biodiversity. The Hawaii field station is developing a mongoose-specific bait station to prevent nontarget species from accessing bait intended for mongooses, as well as conducting field trials to determine the uptake and efficacy of new toxicant baits for mongooses. Long term, the IRC plans to support efforts to eradicate invasive species from larger islands in the tropical Pacific, in the Aleutian Islands, and other parts of the world to help recover native species. NWRC geneticists continue to evaluate and test the applicability of the locally fixed allele approach for gene drives, as well as whether locally fixed allele targets can be identified in island populations of invasive house mice.

SPOTLIGHT: Modeling To Inform Management

The use of models in wildlife management provides valuable information that is often too difficult, time-consuming, or expensive to gather by other means.

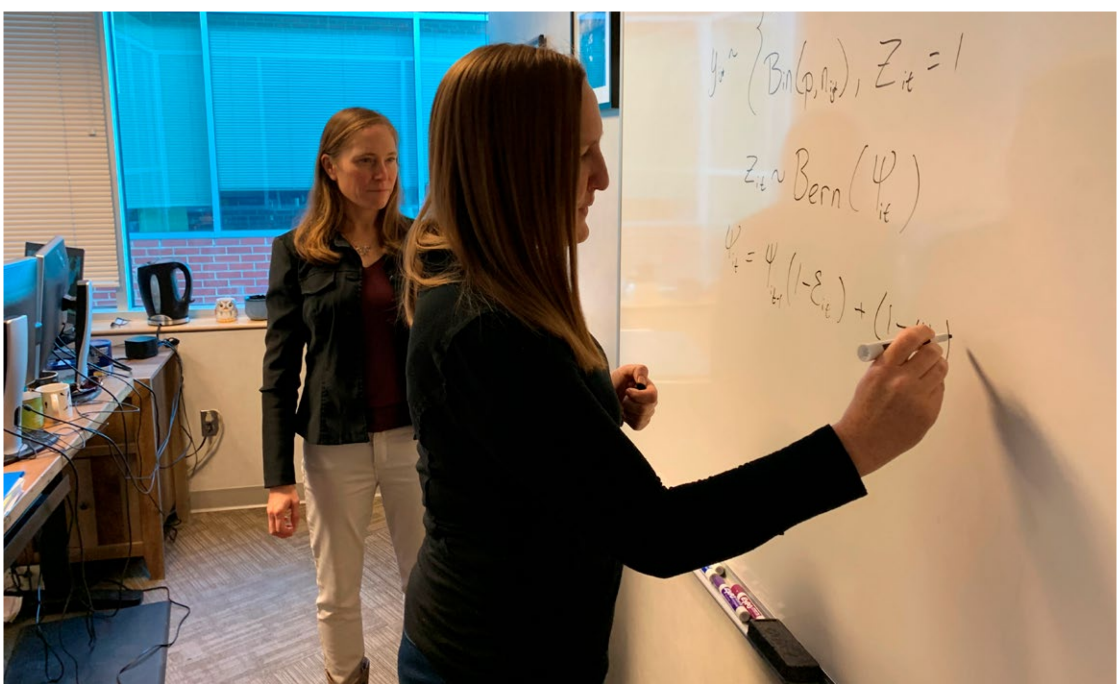
A model is an idea about how a system works. People use models all the time whether they realize it or not. When a wildlife specialist determines the best method to solve an animal damage problem, that is a mental model based on their knowledge and experience. Scientists use mathematical models to help them and others assimilate information and predict an outcome. Models are a thinking tool to help form explanations and anticipate consequences. They are especially useful for helping to see how many different factors interact to produce an outcome. For example, a model could show how current weather conditions, landscape features, and animal behavior together determine the best location to place a trap.

Machine learning is a specific type of model based on artificial intelligence that produces increasingly better models through learning from data. Examples of machine learning include facial recognition, speech recognition, unwanted email (spam) filters, and disease diagnosis. A computer is programmed to look for similarities or patterns in data to help it recognize a particular pattern in the future, and the program increasingly improves with experience.

WS NWRC researchers are using the power of models, including machine learning, to address many challenging and complex questions related to wildlife damage and disease management.

Models Shed Light on Dynamic and Complicated Systems

NWRC researchers are no strangers to models and modeling. Much of their research is devoted to obtaining answers from complex data sets and ecological systems using a



NWRC researchers are using the power of models and machine learning to address many challenging and complex questions about wildlife damage and disease management.
Photo: USDA, Gail Keirn

Wildlife management continues to evolve as scientists leverage the power of models and machine learning.

Feral swine cause damage to newly planted corn. NWRC modelers are predicting how the availability of crops and natural forage might influence feral swine crop damage. The information helps wildlife managers focus damage control efforts in crops where they are likely to have the biggest impact.
Photo: USDA, Wildlife Services

variety of modeling techniques. Models help to answer questions, such as: How does disease spread through a wildlife population? How might wildlife damage to crops affect the regional economy? Which is more cost effective—corral traps or aerial operations? and Which data should be collected to best inform management decisions?

"One of our recent projects used a spatially explicit population model to look at feral swine and their visitation and use of various agricultural crops and natural resources," says NWRC computational biologist Dr. Kim Pepin. "We combined movement data from more than 300 collared feral swine from 24 different studies with data from USDA annual crop records to learn about pig preferences."

Predicting how the availability of crops and natural forage (i.e., grasses, acorns, bulbs, mushrooms, and eggs and other animal matter) might influence crop visitation helps wildlife managers develop efficient control and damage assessment tools and strategies.

"Our hope is that these findings will help WS Operations, landowners, and others prioritize limited management resources to areas where swine are more likely to be active. For instance, the data show swine strongly prefer peach and cotton crops, but not soybeans in South Carolina relative to the crops' overall availability in the State. Managers may decide to focus monitoring and control activities in these crops where they are likely to have a bigger impact," continues Pepin.

NWRC researchers are working with the National Rabies Management Program to evaluate the effectiveness of different rabies surveillance strategies.
Photo: USDA, R. Anson Eaglin

Eventually, the methodology used in this model to predict visitation and preferences could be paired with other data to predict damage levels from feral swine (*Sus scrofa*) population estimates—useful information in building support for feral swine damage management.

WS NWRC researchers are also using models to help the WS National Rabies Management Program (NRMP) evaluate program objectives and improve operational efficiency. The goal of the NRMP is to prevent the spread of and eventually eliminate wildlife rabies in the United States.

"We worked with WS rabies experts and others to evaluate the effectiveness of different rabies surveillance strategies to ensure sufficient allocation of the program's surveillance resources. This involved statistical analysis of the program's surveillance data using an ecological model," says NWRC computational biologist Dr. Amy Davis.

The model estimates and maps occurrence patterns over space and time—in this case, the occurrence of rabies. This collaborative approach helped inform oral rabies vaccine (ORV) zone placement in Ohio, West Virginia, and Pennsylvania to prevent and control rabies in wildlife. It also contributed to management decisions in New York, Vermont, and New Hampshire that resulted in moving the ORV zone 20 miles south of the Quebec border to prevent the international spread of raccoon rabies.

"These targeted approaches are helping to improve WS' efforts on the ground," says Davis.

Informing Management and Registration of New Tools

WS NWRC modelers partnered with WS personnel in Texas to evaluate the effectiveness of aerial operations (gunning) at managing feral swine damage. WS personnel in Texas conducted repeated aerial operations over 3 days at three different study sites. NWRC researchers estimated feral swine abundances before and after each aerial operation (pass), as well as effects of vegetation cover and pilot/gunner teams on effectiveness. Population modeling estimated the proportion of pigs removed from the population and the time it took for the population to recover. Three possible damage-density relationships were used to determine the overall cost effectiveness of the operational activities. Results showed that aerial operations are generally cost effective in areas with damage costs that exceed $20,000, but at least 60 percent of the feral swine population needs to be removed in areas that are sensitive to feral swine damage, such as agricultural crops.

"Flying the same property multiple times over several weeks or months can be cost effective and has longer lasting benefits than only flying once and having to return to the same property year after year," says Davis. "As expected by WS managers, removal rates of feral swine were higher in areas with low amounts of vegetation versus areas of dense vegetation where pigs can easily hide."

Another application for models is in assessing risk and evaluating new tools that are not yet registered for use. The development and registration of new wildlife damage management tools can be time-consuming, challenging, and costly. Through models, researchers can run simulations to identify which pieces of information are most valuable to measure in field studies, quantify or uncover unforeseen risk factors, or evaluate potential effectiveness up front. This can help refine a tool before registration and allow wildlife specialists to hit the ground running when it finally becomes available.

For instance, NWRC modelers worked closely with the NWRC Feral Swine Project to identify cost-effective ways to deliver a feral swine toxicant if and when it is registered for use. Results showed that, once feral swine densities became low, baiting cost effectiveness declined significantly due to the increased effort needed to locate target animals. Under these circumstances, baiting may benefit from the addition of other management methods, such as aerial operations. For more information, please see "Optimizing Control Methods" in the feral swine spotlight on page 23.

Machine Learning To Detect Feral Swine

Invasive feral swine have been reported in at least 31 States. The U.S. feral swine population is estimated at approximately 6 million. Knowing where and how many feral swine are in an area can help wildlife managers and landowners allocate the right resources for damage management or eradication. But locating secretive and often nocturnal feral swine can be like searching for a needle in a haystack.

"WS and others use motion-activated cameras (also known as camera traps or trail cameras) to remotely observe wildlife, including feral swine," says NWRC research wildlife biologist Dr. Kurt VerCauteren. "However, camera traps result in millions of images that must be viewed in order to extract data for ecological analyses. Machine learning saves us time by reviewing and classifying images for us."

NWRC and APHIS' Veterinary Services, as well as State, non-profit, and university partners, used more than 3 million known wildlife images to train and test a deep-learning model to classify species of wildlife captured on camera traps. In particular, the researchers wanted to train the model to distinguish feral swine from other wildlife, such as bears, raccoons, and coyotes.

The trained model classified approximately 2,000 images per minute and achieved 98-percent accuracy in identifying U.S. wildlife species, the highest accuracy of such a model to date. The tool is available as an R package (Machine Learning for Wildlife Image Classification) that allows users to either work with the existing trained model or train their own model using images of wildlife from their studies.

"NWRC is using the trained model to evaluate images taken from camera traps at bait station prototypes designed for feral swine," says VerCauteren. "We're able to select and review only those images identified by the model as feral swine, as well as nontarget species of interest, such as bears. It speeds up our analysis and evaluation of the types of wildlife attracted to and accessing the bait stations, which aids in our bait station design."

Next Steps—NWRC researchers are developing models to predict feral swine population growth and expansion and the impacts of associated management efforts. Models are also being developed to better understand the spread of wildlife diseases, such as African swine fever, bovine tuberculosis, and rabies, and identify optimal control strategies. These modeling efforts involve large collaborations with field biologists and managers across academic institutions and Federal and State agencies to develop robust, data-based tools for risk assessment, surveillance design, and response planning.

Using images from trail cameras, NWRC researchers and partners trained and tested a deep learning model to distinguish images of feral swine from other wildlife, such as bears (pictured), raccoons, and coyotes.
Photo: USDA, Wildlife Services

WS NWRC supports the WS National Rabies Management Program and its partners in their efforts to prevent the spread of wildlife rabies and eventually eliminate terrestrial rabies in the United States.

SPOTLIGHT: Managing Wildlife Rabies

Rabies is an acute, fatal viral disease that can infect all mammals, including people. The impact of rabies on society can be great, especially in underdeveloped countries. The cost of rabies detection, prevention, and control in the United States alone exceeds $600 million annually.

Approximately 90 percent of the reported rabies cases in the United States occur in wildlife. Raccoons, skunks, bats, foxes, and coyotes are among those most commonly infected. Since 1995, WS has been working cooperatively with Federal, State, and local agencies; universities; and other partners to prevent the spread and reduce the prevalence of rabies in specific wildlife populations. Each year, WS and cooperators distribute more than 8 million oral rabies vaccine (ORV) baits across 17 States to create vaccination zones that prevent the spread of raccoon rabies virus.

"Although human rabies deaths are now rare in the United States, there still are significant impacts associated with the disease, particularly to people, pets, and livestock," says WS NWRC research biologist Dr. Amy Gilbert. "Among the various wildlife rabies reservoirs in the United States, raccoons have the highest rate of spillover infections to domestic animals and wildlife, and consequently are associated with the greatest burden of human exposures which require post-exposure treatment."

Current data estimate approximately 55,000 individuals seek post-exposure treatment in the United States each year, with cumulative costs in excess of $200 million. If rabies virus variants such as those transmitted by raccoons are not prevented from spreading to new areas of the United States, the health threats and costs from rabies could increase substantially.

Approximately 90 percent of reported rabies cases in the United States occur in wildlife. Raccoons (pictured), skunks, bats, foxes, and coyotes are among those most commonly infected.
Photo: Adobe Stock

WS NWRC's development of new tools and techniques and its evaluation of disease management strategies supports the WS National Rabies Management Program (NRMP) and its mission to prevent the spread of wildlife rabies and protect U.S. public health, agriculture, and natural resources.

Improving Vaccine Baits and Baiting Strategies

Since the start of the NRMP, NWRC researchers have helped the program identify, evaluate, and refine its ORV baits and baiting strategies. Recent efforts have focused on evaluating a new vaccine bait called the Ontario Rabies Vaccine Bait (ONRAB), which has shown promise for controlling rabies in raccoons and striped skunks in Canada. Efficacy data from NWRC studies were submitted to the USDA Center for Veterinary Biologics in support of registering ONRAB for use in the United States.

Other work has focused on improving bait uptake by striped skunks, an important spillover host of raccoon rabies. NWRC researchers tested skunks' preference for six different flavors of placebo ONRAB baits. The researchers also tested the dose of ONRAB vaccine needed to protect the skunks from rabies infection to help evaluate if it is possible to reduce the vaccine volume and dose without compromising efficacy. Results showed that skunks preferred chicken, cheese, and egg flavors over the plain flavor, but they did not show strong flavor preferences. Also, a relatively high dose of vaccine delivered orally was needed to protect skunks against rabies. These findings aid in further refining ORV baits for skunks to enhance raccoon rabies virus management in the Eastern United States.

Effective vaccine baiting strategies require an accurate estimate of the target species' population density. Because it is hard to obtain accurate population density information across broad landscapes, typical NRMP baiting application strategies for raccoons are

NWRC researchers are working to improve oral rabies vaccine bait uptake by striped skunk, an important spillover host of raccoon rabies.
Photo: Adobe Stock

75 baits/kilometer (km)^2 in more rural landscapes and 150/km^2 in suburban and urban landscapes where raccoon densities are known or suspected to be high or there is a generally poorer immune response to ORV. To evaluate the effectiveness of existing bait density strategies across areas of the Eastern United States managed with ORV, NRMP and NWRC experts indexed raccoon population densities based on a standardized trap survey protocol used from Maine to Alabama. Researchers and managers then compared the density indices to more robust mark-recapture density estimates.

Overall, raccoon density indexes (RDI) ranged from 0 to 56.9 raccoons/km^2. NWRC researchers evaluated RDIs in four raccoon density groups that align with thresholds used by managers in ORV planning: 0.0–5, 5.1–15, 15.1–25, and >25 raccoons/km^2. They concluded that the four density groups were of an appropriate scale to aid in ORV baiting decisions and that the RDIs aligned well with mark-recapture density estimates. Researchers conclude that RDIs are a cost-effective way of providing comparable population density estimates across broad landscapes to aid in rabies management planning and decision making.

In a related study, NWRC researchers compared results from two different ORV baiting efforts in West Virginia. ONRAB baits were distributed for 2 years at 75 baits/km^2 followed by 3 years at 300 baits/km^2. Changes in rabies virus neutralizing antibody (RVNA) seroprevalence, which may indicate successful vaccination in targeted raccoon and striped skunk populations, were compared each year before and after bait distribution. The increase in bait density from 75/km^2 to 300/km^2 corresponded to an increase in seroprevalence for raccoon and skunk populations. In raccoons, the average

RVNA levels increased from 53 to 82 percent during the study, and in skunks, the average RVNA levels increased from 11 to 39 percent. Results indicate that it may take multiple years of ORV baiting to maintain the levels of protection needed in targeted wildlife populations for eliminating raccoon rabies virus in the Eastern United States.

In other studies, NWRC researchers explored how movement and contact among animals, along with variations in their foraging and social behaviors, can influence the spread and intensity of wildlife disease outbreaks. Using raccoons and rabies as a case study, researchers partnered with Colorado State University and the NRMP to simulate the effect of differences in home range behavior on the spread, persistence, and incidence of the rabies virus in raccoon populations, as well as its impact on the effectiveness of ORV programs.

Results showed that variation in the weekly home range of raccoons increased rabies virus spread rates 1.2- to 5.2-fold compared to static home range behaviors. Variable home range behaviors also decreased ORV effectiveness by 71 percent. The ORV campaign timing (i.e., season) was more impactful for ORV effectiveness than either campaign frequency or the width of the vaccination barrier zones.

Given that a few individual animals may disproportionately influence the success or failure of an ORV program, researchers note that efforts to better understand what drives variation in raccoon movements should be a priority, especially in both rural and urban landscapes. Understanding how variations in animal home range behavior and habitat use impact wildlife disease dynamics could help efforts to prevent and control the spread of wildlife diseases and refine landscape management strategies.

Rabies Management in Mongooses

The small Indian mongoose is an invasive species in Puerto Rico. Mongooses were introduced to the island during the 19th century to control rats on sugar cane plantations. Since then, they have become agricultural pests on the island and serve as a reservoir for rabies virus.

"Mongooses account for 40 to 80 percent of the reported rabies cases in Puerto Rico," notes NWRC biologist Are Berentsen, who has been studying mongooses on Puerto Rico and other islands.

Two human fatalities have occurred from mongoose-variant rabies virus in Puerto Rico during the 21st century. The most recent case occurred in 2015 and was transmitted by a mongoose bite. Currently, no wildlife rabies vaccination program exists on the island, and the vaccination of pets and domestic animals may be limited.

In the continental United States, the NRMP coordinates efforts to prevent the spread of rabies in wild carnivore populations. These efforts consist primarily of enhanced rabies surveillance and broad distribution of ORV, complemented with trap-vaccinate-release activities targeting high-risk areas. To develop a rabies surveillance and control program for mongooses in Puerto Rico, the NRMP must first understand several factors: mongoose population density, home range behavior and habitat use, exposures to rabies virus, effective bait formulations and delivery mechanisms, and potential nontarget hazards and public health and environmental risks.

Starting in 2011, NWRC and NRMP experts began efforts to gather this information. Field studies in Puerto Rico found mongoose population densities ranged from 44 to 75 mongooses/km^2 depending on the season,

Oral rabies vaccination studies and assessments in Puerto Rico are targeting rabies in invasive mongooses.
Photo: USDA, Wildlife Services

with home range estimates up to 1.5 km^2. Furthermore, blood samples collected from free-ranging mongooses showed that in some habitats up to 39 percent of mongooses captured had prior exposure to the rabies virus. In bait flavor trials, mongooses preferred egg-flavored baits, and the primary nontarget competitors for the baits were invasive rodents.

With many of the basic questions about mongoose populations answered, NWRC and NRMP began field trials in fall 2016 at the Cabo Rojo National Wildlife Refuge and a nearby private property, using placebo ORV bait with iophenoxic acid as a biomarker. Results showed that 63 percent of the 87 mongooses captured after the ORV application contained biomarker residues in their blood, indicating that they had eaten the bait. In spring 2017, a second placebo bait application occurred to evaluate seasonal changes in bait uptake by mongooses; 69 percent of the 123 mongooses sampled were positive for the biomarker.

NWRC researchers are collaborating with other experts to broaden their understanding of mongoose and rabies ecology in the Caribbean. In addition, NWRC and University of Montreal scientists are studying domestic dogs and mongoose interactions and the role these interactions may play in rabies virus transmission to people. A limited field vaccine trial, the first of its kind for mongooses, is tentatively planned for fall 2021.

Vampire Bait Surveillance in the United States

The common vampire bat (*Desmodus rotundus*) feeds on the blood of livestock, other domestic animals, and wildlife in Latin America. These bats also sometimes feed on human blood and are an important reservoir and vector of rabies virus to cattle and people in Latin America. Recently, vampire bats have been documented within 35 miles of the Texas border. This and ecological habitat modeling have led to speculation about their potential movement to areas within the United States, due in part to rising global temperatures.

Injuries from bites and the fear of rabies virus transmission, economic impacts, and biodiversity losses from nontarget hazards to other bat species are some of the concerns associated with vampire bats. Past and current methods of controlling their damage involve reducing local bat populations with anti-coagulant pesticides and vaccinating livestock and other domestic animals against rabies. However, even under optimal conditions, the results of these methods may be short-lived and may negatively impact other bat species that share roosts with vampire bats. Research and development using modern technologies to deliver specific, effective, and sustainable strategies for vampire bat rabies control are needed.

Recently, vampire bats have been documented within 35 miles of the Texas border. In several Southern U.S. States, WS biologists are monitoring livestock at centralized locations for evidence of vampire bat bites, which may serve as an early warning indicator of vampire bat establishments in the United States.
Photo: USDA, Amy Gilbert

The WS NRMP, WS NWRC researchers, WS Operations, and partners are using a multi-disciplinary approach that includes enhanced surveillance, targeted risk assessments, habitat modification, and renewed research and collaborations, as well as greater public and professional awareness, education, and outreach. In Texas, Arizona, New Mexico, and Florida, WS biologists are monitoring livestock at centralized locations for evidence of vampire bat bites, which may serve as an early warning indicator of vampire bat establishments in the United States. Since 2016, WS has conducted more than 800 surveys at livestock sales barns, ranches, feedlots, and dairy barns and inspected more than 300,000 cattle. WS has found no evidence of bat bites during these surveys. Furthermore, WS partnered with APHIS International Services in Mexico to conduct targeted outreach efforts with livestock producers near the border who are likely to be impacted in the potential northern range expansion of vampire bats.

In 2020, the NRMP and NWRC hosted an expert Blue-Ribbon Panel to discuss risk assessment and best practices related to vampire bat rabies virus surveillance and monitoring. The panel included 34 experts representing 20 agencies and organizations. Outcomes from the event included a report summarizing the experts' opinions on a range of issues, including: the likelihood that vampire bats will expand to the United States in the near future, the main risks posed by vampire bats, the surveillance methods most likely to detect vampire bats and the vampire bat rabies virus variant, and potential vampire bat management methods.

Next Steps—NWRC researchers are continuing to design and refine effective surveillance strategies to detect declining levels of raccoon rabies prevalence and to quantify the relationship between successful vaccination of wildlife (i.e., rabies antibody seroprevalence in targeted species) and the reduction of rabies cases in the United States. In collaboration with a variety of industry and Federal partners, NWRC researchers are evaluating next-generation wildlife ORV products, as well as new delivery strategies for existing ORV products.

SPOTLIGHT: Update on Feral Swine Research

Started in 2014, the National Feral Swine Damage Management Program (NFSDMP) coordinates and carries out control activities to reduce feral swine damage across the United States and its territories. Feral swine are one of the world's worst invasive species. They cause major damage to property, agriculture, and native ecosystems; prey on or compete with native wildlife; and spread diseases. The current population of feral swine in the United States is an estimated 6 million and would continue to expand without control efforts.

WS NWRC research supports the NFSDMP. Recent work focuses on developing a feral swine toxicant, optimizing control methods, monitoring feral swine populations, assessing damage to agriculture and natural resources, and understanding public perceptions about feral swine. The following summaries give an update on some of these research efforts.

Toxicant Development

NWRC researchers and collaborators have been evaluating sodium nitrite for use as a feral swine toxicant.

After they completed studies with captive feral swine that assessed the toxicant's effectiveness and humaneness, the U.S. Environmental Protection Agency (EPA) granted an Experimental Use Permit in spring 2018, and a field trial of a sodium nitrite bait called HOGGONE began. Researchers halted the trial when they noticed that bait crumbs left outside of bait stations by feral swine posed a risk to nontarget species, mainly seed-eating birds. Even with the abbreviated effort, researchers documented a 66-percent mortality rate in free-roaming feral swine from 1 to 2 nights of toxic baiting. Researchers identified issues with the bait and baiting strategies and set out to develop strategies to maximize efficacy on feral swine while reducing risks to nontarget species.

Aerial view of feral swine rooting damage to pastures. Feral swine are considered one of the most destructive invasive species in the United States due in part to their rooting behavior. The species costs the United States an estimated $1.5 billion each year in damages and control costs.
Photo: USDA, Wildlife Services

WS NWRC research supports the National Feral Swine Damage Management Program by working to improve the efficiency of existing control methods and developing new management strategies.

"We worked with the manufacturer to reformulate the bait to reduce nontarget risks by increasing its palatability to feral swine and reducing spillage," explains research wildlife biologist and feral swine project leader Dr. Kurt VerCauteren. "We also reassessed our baiting strategies and bait station designs to further target feral swine and prevent access to bait by nontarget species."

The new formulation, known as HOGGONE 2, was first tested in December 2018 in Queensland, Australia. Additional field trials took place in Alabama and Texas in 2019 and 2020. These field trials evaluated hazards associated with toxic bait spillage outside of bait stations and whether nontarget species could breach bait stations. The trials also assessed the lethality of HOGGONE 2 and new baiting applications for free-ranging feral swine.

Preliminary results from HOGGONE 2 showed that just one night of toxic baiting reduced feral swine populations by 78 to 90 percent. However, despite much lower amounts of toxic bait being spilled outside of the bait station by feral swine, there were still some nontarget mortalities (mainly seed-eating birds). Subsequent testing of scare devices and chemical repellents showed that an inflatable scarecrow effectively deterred nontarget species from using the bait sites. Then, researchers conducted another study using the inflatable scarecrow and toxic HOGGONE 2 in Texas, which revealed a 91-percent reduction in feral swine in 1 night and no nontarget species deaths. Given these positive results, researchers are pursuing EPA registration of the sodium nitrite bait for use with feral swine.

Optimizing Control Methods

Along with efforts to develop a toxicant and feral swine-specific bait station, NWRC researchers are identifying cost-effective strategies for optimizing toxicant delivery.

"Baiting is a common method for delivering toxicants to help control wildlife populations," says research biologist Dr. Kim Pepin. "Knowing how many and where to place baits on the landscape is crucial to the success of these efforts and can be influenced by factors such as bait attractiveness, animal movement, habitat diversity, time of year, and duration of the baiting effort."

NWRC researchers developed a model to predict the optimal baiting strategy for the sodium nitrite-based toxicant under development using data on feral swine bait consumption and mortality probabilities.

"Basically, we're looking for the baiting strategy that gives us the best results at the least cost," continues Pepin.

Results showed a wide range of baiting strategies were cost effective when the objective was 80-percent population reduction. In contrast, only a narrow range of baiting strategies allowed for a 99-percent population reduction. When feral swine densities were low, baiting cost effectiveness declined because of the increased effort needed to locate target animals.

Bait avoidance as a result of sublethal dosing had only minor effects on cost effectiveness when the objective was an 80-percent population reduction but was much stronger when the objective was 99-percent population reduction. Researchers conclude that toxic bait to control feral swine is most cost effective when used to reduce high-density populations by substantial amounts. They also note baiting may benefit from the addition of other management strategies, such as aerial operations, when the goal is complete population removal.

Along with finding optimal baiting strategies, researchers are also interested in cost-effective ways to estimate feral swine populations.

"You can't manage what you don't measure," notes VerCauteren. "NWRC is supporting the National Feral Swine Damage Management Program by finding ways to estimate feral swine population densities."

For example, NWRC and University of Georgia researchers compared the cost effectiveness of three common methods for estimating feral swine populations. The methods included: (1) mark-recapture analysis of fecal deoxyribonucleic acid (DNA) sampling, (2) spatially explicit capture-recapture analysis using images from trail cameras, and (3) removal analysis based on trapping.

NWRC researchers are using trail cameras to capture images of feral swine in order to estimate feral swine population densities.
Photo: USDA, Wildlife Services

Resulting feral swine density estimates were similar across the three methods. Camera sampling was the least expensive method but had large variations in its estimates. Fecal DNA sampling was the most expensive method but performed well.

Researchers also investigated ways to reduce implementation costs without adding bias or imprecision to the estimates. Results showed that simply reducing the number of traps could reduce the cost of removal sampling via trapping and still maintain unbiased estimates. Costs for fecal DNA sampling or camera sampling could only be reduced slightly before introducing bias. A decision tree was created to guide future research and use of the three population estimation methods.

Genetics

Genomics—the study of genes and their functions—and novel genetic tools such as environmental DNA sampling are providing valuable information on feral swine and their impacts to natural resources and agriculture. NWRC geneticists are working with the NFSDMP to analyze the diet of feral swine, assess their genetic ancestry in North America, detect feral swine movements through human-mediated transport, and evaluate the success of feral swine eradication efforts.

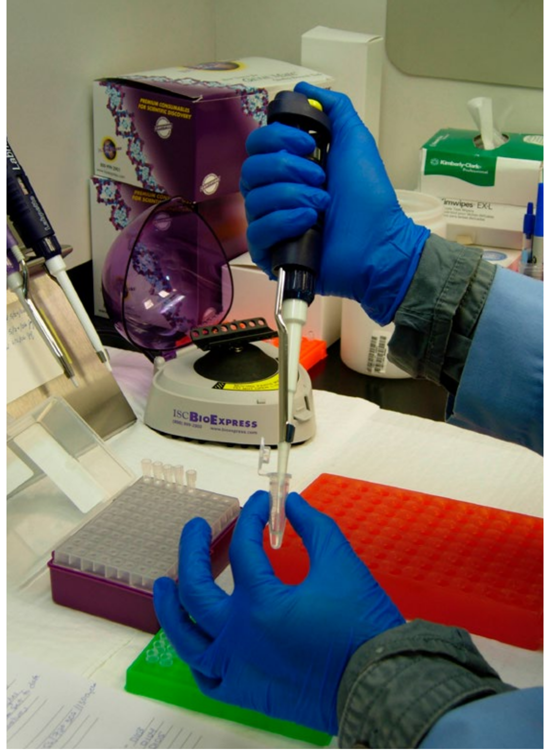
Although many feral swine impacts are easy to see and document, their foraging and predation impacts on plants and animals are harder to quantify. Traditional diet analysis of feral swine stomach contents has shown they feed on rodents, amphibians, and young deer. However, easily digested items, such as bird eggs, are difficult to detect with traditional analyses. NWRC geneticists used genomics to sequence and identify multiple items from the stomach and fecal samples of collected feral swine and discovered feral swine have eaten quail in Texas, imperiled ground squirrels in California, and ecologically valuable wetland plants in Florida.

Feral swine in the contiguous United States date back to 1539 with the introduction of domestic pigs by Spanish explorers. Initial populations were intentionally and accidentally augmented with imported European wild boar to improve their appearance and hunting appeal. NWRC geneticists used cutting-edge tools, like those used by popular ancestry companies, to identify the unique genetic signatures for 6,566 feral swine sampled throughout the United States and compared them to a comprehensive reference set consisting of commercial and heritage pig breeds and wild boar. The geneticists also evaluated whether the recent expansion of feral swine in the United States was the result of increases in established populations or novel introductions from domestic breeds, wild boar, or companion animals.

“We found that only 3 percent of sampled feral swine were the result of new releases or escapes of commercial or heritage domestic breeds, European wild boar, or companion animals,” says Dr. Tim Smyser, an NWRC geneticist. “Instead, the feral swine populations in the United States are the result of admixed ancestry with dominant contributions coming from Western heritage breeds and European wild boar.”

Researchers also determined that the rapid expansion of feral swine seen from the 1980s to 2010 was mainly due to people moving animals from established populations to new habitats, not new introductions of domestic pigs or wild boar. These findings will aid in further developing and adopting management strategies to prevent the spread of invasive feral swine.

Another NWRC contribution to feral swine



NWRC geneticists are analyzing feral swine stomach and fecal contents to learn about their foraging and predation impacts on native plants and animals.
Photo: USDA, Wildlife Services

management is the development of environmental DNA (eDNA) sampling to detect the presence of feral swine on the landscape. eDNA refers to DNA that is shed by an organism into the environment (for example: water, soil, or air). The genetic material could come from mucous, urine, feces, and shed skin, hair, or scales.

NWRC geneticists have developed a polymerase chain reaction (PCR) method to detect feral swine eDNA at low concentrations in turbid waters, such as wallows. This method allows for monitoring the presence-absence of feral swine. For instance, WS biologists and NWRC researchers can sample for eDNA in locations after an eradication effort and locate any last remaining pockets of feral swine. If they detect feral swine DNA, WS experts can increase their monitoring and trapping efforts until remaining swine are removed. This method can also be used to confirm reported sightings in newly invaded areas.

NWRC experts have also improved the usefulness and efficiency of eDNA techniques by determining eDNA detectability limits and degradation rates for different species, evaluating various extraction methods, and improving the ease of field collection and shipment procedures.

Economics and Human Dimensions

Over the past 30 years, feral swine have expanded their range from 17 to at least 31 States. Their spread has inflicted substantial costs on agricultural and livestock producers. NWRC researchers and collaborators are conducting economic damage assessments and public perception surveys to further quantify these costs. Their work will help guide feral swine control efforts and research and serve as a benchmark for measuring the effectiveness of future control efforts.

To date, NWRC economists have collaborated with the USDA National Agricultural Statistics Service (NASS) on three major producer surveys to assess current damage levels. The first survey involved approximately 4,300 producers of corn, soybeans, wheat, rice, peanuts, and sorghum in an 11-State region (Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, and Texas).

"Our results showed that peanut and corn farmers in the Southeast and Texas experienced the highest yield loss from feral swine," says NWRC economist Aaron Anderson. "However, the economic burden from feral swine was not limited to just crop damage. Producers also spent a great deal on damage management and control costs."

Many growers reported using a suite of control methods, including shooting and trapping. The costs of control measures, as well as losses in yield, were substantial for crop producers, many of whom typically operate on very small profit margins. Survey results indicate that feral swine damage to these crops exceeded $190 million in the United States in 2015. Though large, this number likely represents only a small fraction of the total damage by feral swine because it includes damage to only six crops.

Building on these results, NWRC economists worked with NASS to conduct a complementary survey to estimate feral swine impacts to six other crops: hay, pecans, melons, sugarcane, sweet potatoes, and cotton in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, and Texas. Also, in California, economists looked at the impacts to hay, almonds, grapes, sod, carrots, lettuce, and strawberries. Nearly 7,500 farmers were surveyed overall. The highest yield loss occurred for hay in Texas. When NWRC economists extrapolated the damage estimates from all six crops across the entire 12-State region, they estimated a total production loss of nearly $272 million in 2019.

A separate survey investigated the impacts of feral swine damage to livestock production, including the spread of disease, predation on livestock, and impacts to international trade. More than 6,300 livestock producers responded from 13 States (Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas). Results showed that damage to cattle operations in Texas and Arkansas was substantially higher than damage in other States and types of livestock operations. When extrapolated to livestock producers across the entire 13-State region, NWRC economists estimated that feral swine caused $40 million in livestock predation and disease damages in 2017.

Understanding how the public and key stakeholders feel about feral swine and their preferences for managing damage is important for wildlife managers and other decision makers. This information helps shape management priorities and enhance outreach efforts. NWRC research on human dimensions

Understanding how livestock producers and others feel about feral swine and their preferences for managing damage helps shape management priorities and public outreach efforts.
Photo: USDA, Wildlife Services

and public perceptions reveals that much of the U.S. public holds an unfavorable view of feral swine and supports legal restrictions on their transport and most methods of lethal control. One significant exception is that a majority of the public, including people in States with feral swine, oppose the use of toxicants because of concerns about potential nontarget hazards, pain and suffering by feral swine, impacts to soil and water, and the possible tainting of meat intended for human consumption. These insights are helping to guide NWRC's research and development efforts related to a toxicant bait and feral swine-specific bait stations.

Comprehensive Book on Feral Swine

WS field specialists, biologists, and researchers have been involved in feral swine damage management and research for more than a decade. Much of what they and others have learned is now available in a new reference book titled *Invasive Wild Pigs in North America: Ecology, Impacts and Management* (CRC Press). The 480-page book covers all aspects of feral swine biology, ecology, history, and strategies for management, as well as information on feral swine impacts to natural resource and agriculture. Chapters are written by WS NWRC scientists, WS Operations, and other feral swine experts. Copies of many of the book's chapters and other original peer-reviewed manuscripts related to feral swine research can be downloaded from the NWRC Digital Collections at https://nwrc.contentdm.oclc.org/digital. Click on "NWRC Publications" and enter *"Invasive Wild Pigs in North America: Ecology, Impacts and Management"* in the search box at the top right of the page.

Next Steps—NWRC researchers continue to evaluate, refine, and optimize tools for feral swine damage management. In addition, they are developing new monitoring strategies to assess the size of feral swine populations and measure the agricultural and natural resource benefits of removing feral swine from the landscape. An extension of this research focuses on strategies to best detect feral swine reinvasions.

2020 Accomplishments in Brief

Double-crested cormorant with catfish
Photo: Adobe Stock

WS NWRC employs about 150 scientists, technicians, and support staff who are devoted to 16 research projects (see Appendix 1). Below are brief summaries of select findings and accomplishments from 2020 not already mentioned in this year's report.

Devices

- **Vehicle-Based Lighting System To Reduce Deer-Vehicle Collisions.** Published estimates suggest there are more than 1.5 million deer-vehicle collisions each year in the United States, causing over 100 human deaths, thousands of personal injuries, and $1 billion in vehicle damages. To reduce deer-vehicle collisions during low-light conditions, NWRC researchers built upon methods and findings from their past work on animal responses to approaching vehicles and various lighting effects. Yet unlike past work, the methodology this time included a rear-facing light-emitting diode (LED) light bar which illuminated a larger portion of the vehicle's front surface than standard headlights alone. The researchers conducted a series of experiments with free-roaming white-tailed deer to test this methodology.

  Results showed the likelihood of dangerous deer-vehicle interactions decreased from 35 percent to only 10 percent when using a rear-facing LED light bar plus headlights versus just headlights alone. The reduction in dangerous interactions appeared to be driven by fewer instances of immobility or "freezing" behavior by deer when the light

A new patent-pending methodology (U.S. Patent Application No. 16/668,253) developed by NWRC researchers reduces deer-vehicle collisions by using a rear-facing light-emitting diode (LED) light bar. The bar illuminates a larger portion of a vehicle's front surface than standard headlights alone, helping deer to better detect and respond to an approaching vehicle.
Photo: USDA, Travis DeVault

bar was used. The new lighting system takes advantage of a deer's predator avoidance behavior (also known as flight behavior). Light reflected from the front surface of the vehicle provides a more reliable looming image to deer, thus encouraging the deer to move out of the path of the approaching vehicle. When an object "looms," the animal perceives it as becoming increasingly larger, helping them realize that the object is approaching versus one that is stationary. This patent-pending methodology (U.S. Patent Application No. 16/668,253) can be developed as an after-market device, like a brush guard or bumper, or can be embedded in a vehicle as part of the manufacturing process.

Contact: Brad Blackwell

Pesticides

- **How Acetaminophen Works on Invasive Brown Tree Snakes.** Since 2003, acetaminophen (a common pain medication for people) has been registered by the U.S. Environmental Protection Agency (EPA) as an oral toxicant for invasive brown tree snakes on Guam. Though it is known that a low dose (80 mg) of the chemical is lethal to the snakes, until now, scientists were unsure how it actually caused the snakes' death. NWRC researchers recently conducted physiological analysis of brown tree snakes treated with a lethal dose of acetaminophen and found the cause of death to be acute methemoglobinemia and respiratory failure. Methemoglobin is a form of hemoglobin that occurs naturally at low levels in the blood. Methemoglobinemia occurs when methemoglobin levels are elevated and begin to interfere with oxygen transport and delivery, leading to a lack of oxygen reaching the body's cells. Of the 71 treated brown tree snakes used in the analysis, none showed signs of distress or pain. They became lethargic and unresponsive just before death. Findings suggest that acetaminophen is a humane method for lethally controlling invasive brown tree snakes.

  Contact: Rick Mauldin

- **Reduced Effectiveness of Rodenticides.** California ground squirrels (*Otospermophilus beecheyi*) can damage rangeland and agricultural crops, such as tree fruits and nuts. In California, ground squirrels are often managed with bait stations that continuously deliver diphacinone or chlorophacinone, both first-generation anticoagulant rodenticides. Recently, agricultural producers have reported low efficacy of these compounds in field uses. Previous rodenticide research has shown that an increase in an animal's metabolic activity may be associated with anticoagulant resistance. NWRC researchers examined liver metabolism of diphacinone and chlorophacinone using microsome isolations from ground squirrels captured in areas with and without the use of these anticoagulants. Contrary to what was expected, results showed male squirrels from anticoagulant-exposed areas had a significant decrease in metabolic activity. This indicates the cause of decreased anticoagulant rodenticide efficacy in ground squirrels may not be increased metabolism, but instead other physiological (i.e., genetic resistance) or behavioral (i.e., bait avoidance) factors.

  Contact: Katherine Horak

- **American Kestrel Exposure to Anticoagulant Rodenticides.** Reports documenting the presence of anticoagulant rodenticide residues in the tissues of nontarget predatory or scavenging birds and mammals are increasing. To gain a better understanding of the long-term effects of rodenticide exposure and residue burdens on physiological functions and the overall fitness of individual animals, NWRC, U.S. Geological Survey, and University of Maryland researchers conducted a series of studies with captive American kestrels (*Falco sparverius*). The researchers collected data on toxicity, liver residues, and the recovery of the birds after exposure to brodifacoum-treated meat. Brodifacoum is a commonly used second-generation anticoagulant rodenticide.

Findings showed American kestrels exposed to environmentally realistic concentrations of brodifacoum experienced dose-dependent effects on blood clotting, such as bruising, hemorrhaging, prolonged clotting time, and anemia. Once exposure was stopped, blood clotting time returned to normal within 1 week, but brodifacoum residues in the liver and kidneys persisted throughout a 28-day recovery period. Subsequent repeat exposure to brodifacoum prolonged prothrombin time (how quickly the blood clots) in exposed birds compared to non-exposed birds or those exposed to a first-generation anticoagulant rodenticide. These findings provide evidence that brodifacoum may have prolonged effects that increase the toxicity of subsequent anticoagulant rodenticide exposure. Because free-ranging predatory and scavenging wildlife are often repeatedly exposed to anticoagulant rodenticides, such effects need to be considered in hazard and risk assessments.

Contact: Katherine Horak

- **Secondary Hazards to Geese From Rodenticide.** Introduced rodents, especially rats, cause a wide array of conservation problems in the Hawaiian Islands and on other islands. However, there are concerns about nontarget hazards when using rodenticides to remove invasive rodents. NWRC researchers evaluated the acceptability and toxicity of two pelleted forms of 0.0005-percent diphacinone rodenticide baits to Canada geese (*Branta canadensis*), a surrogate species for the endangered Hawaiian goose (*Branta sandvicensis*). Based on trials with captive Canada geese, neither the whole nor the chopped rodenticide pellets pose a significant risk to the Hawaiian goose, a species considerably smaller than the Canada goose. The pellets were not eaten by the Canada geese during the study despite their having only a small amount of green grass sod as an alternative food. There were no mortalities of geese during the feeding trials, and all geese remained healthy. Researchers conclude the pellets pose a low

To gain a better understanding of the long-term effects of rodenticide exposure and residue burdens on individual animals, NWRC and its partners conducted a series of studies with captive American kestrels.
Photo: Adobe Stock

NWRC researchers evaluated the risks of two pelleted forms of 0.0005-percent diphacinone rodenticide baits to Canada geese, a surrogate species for the endangered Hawaiian goose (pictured).

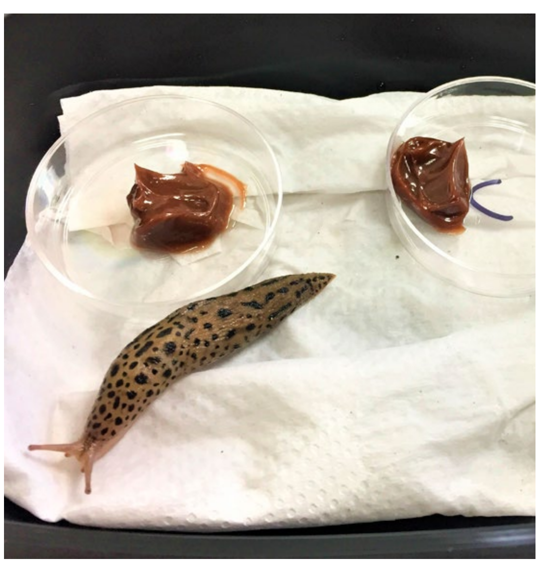
Photo: Adobe Stock

risk to endangered Hawaiian geese and may be a viable option for controlling invasive rodents on conservation lands in Hawaii.

Contact: Gary Witmer

- **Rodenticide Exposure on Reptiles.** To learn more about the risks anticoagulant rodenticides pose to nontarget reptiles, NWRC researchers orally dosed giant ameivas (*Ameiva ameiva*), boa constrictors (*Boa constrictor*), wood turtles (*Rhinoclemmys pulcherrima*), and green iguanas (*Iguana iguana*) with one of two levels of either diphacinone or brodifacoum anticoagulant. Animals were monitored for 14 days for signs of anticoagulant intoxication and differences in behaviors and postures and then euthanized. The animals were necropsied, and both tissue and organ samples were taken for analysis. No turtles or boas died due to anticoagulant exposure. However, anticoagulant intoxication was suspected in one iguana dosed with brodifacoum. A few treated ameivas died but exhibited no hemorrhaging. Turtles and boas exhibited a relative insensitivity to diphacinone and brodifacoum, while the lizards appeared to be somewhat more sensitive to these compounds. This study provides valuable information about secondary risks to these species from anticoagulant use.

  Contact: Rick Mauldin



Rodenticide baiting can be hindered when slugs interfere with bait intended for rodents. In laboratory tests, NWRC and University of Hawaii researchers tested whether adding citric acid to common rodent bait would repel slugs.

Photo: University of Hawaii, Stephanie Joe

- **Rodent Bait With Slug-Repellent Properties.** Bait longevity and attractiveness are keys to successful rodent trapping. In some areas, slugs can hinder baiting success when they interfere with bait intended for rodents. Slugs can eat all or a portion of the bait and make it less attractive to rodents via their slime, and large slugs can trigger traps. NWRC researchers evaluated whether adding food-grade citric acid (up to 5-percent concentration) to common rodent bait would repel slugs. Captive slugs were offered both a treated (0.5–5 percent citric acid added) and control bait. Results showed slugs strongly preferred the control bait (i.e., bait without any citric acid). Adding citric acid may improve the longevity and attractiveness of bait to rodents in slug-inhabited environments, which could aid in rodent control programs.

  Contact: Aaron Shiels

Other Chemical and Biological Methods

- **Oral Contraceptive for Rats.** Over the last 20 years, injectable immunocontraceptives have been widely tested for use in wildlife management. These vaccines work by causing an immune response to proteins or hormones essential for reproduction, such as gonadotrophin-releasing hormone (GnRH). To expand on these tools, NWRC researchers partnered with experts from the United Kingdom and France to develop an oral immunocontraceptive that exploits the bioadhesive and immunological properties of killed *Mycobacterium* avium cell wall fragments (MAF). *M. avium* is a non-pathogenic bacterium commonly found in the environment. Researchers linked MAF to a GnRH recombinant protein called IMX294 to enhance mucosal uptake. The resulting MAF-IMX294 conjugate was given orally to female laboratory rats. Researchers then checked the female rats for a specific immune response to GnRH and paired and mated them with male rats of proven fertility. Results showed evidence of anti-GnRH antibody titers and reduced fertility in the female rats. This is the first time reduced fertility has been produced by an orally delivered immunocontraceptive vaccine. Developing orally delivered immunocontraceptives would greatly increase the applicability of fertility control tools for wildlife management.

  Contact: Doug Eckery

- **Detecting Colistin-Resistant *E. coli* in Feral Swine Feces.** The antibiotic colistin has been used to promote growth in livestock since the 1960s. Since then, colistin resistance in microbes in animal agriculture has increased. Of concern to health experts is the discovery of the gene (*mcr-1*) that confers resistance to colistin and is readily transmitted between different strains of bacteria. Colistin is an antibiotic of last resort used to treat multidrug-resistant bacterial infections in people. NWRC researchers partnered with U.S. Geological Survey, Linköping University, and University of Wyoming experts to develop a method for detecting colistin-resistant *E. coli* containing *mrc-1* in the feces of feral swine, a known wildlife host of bacteria with *mcr-1*. This study evaluated multiple selective enrichment strategies to allow for the growth of the target bacteria in swine feces and then utilized a real-time polymerase chain reaction (PCR) assay to detect the colistin resistance determinant *mcr-1* within the enrichments. The method is simple and cost effective, limiting the need for multistep enrichments and extensive nucleic acid preparation steps. This new technique can be used for national-level monitoring of *mcr-1 E. coli* in feral swine, which may be an important host for maintaining and spreading these potentially dangerous bacteria.

  Contact: Jeff Chandler

- **Predicting Whole Genome Sequencing Success for Archived Samples.** Whole genome sequencing (determining an organism's complete DNA or RNA sequence) has become a standard tool for studying viruses. The data is useful for understanding virus biology, such as their molecular evolution and ability to switch hosts and cause disease. Failure to obtain complete viral genomes from a given sample is tied to many factors, such as sample integrity and preservation methods. The capacity to prescreen viral samples before whole genome sequencing could help prioritize samples and reduce the amount of time and resources used on unproductive or low yield samples.

Using wild bird samples from avian influenza viruses stored in the WS National Wildlife Disease Program Wildlife Tissue Archive, WS NWRC and Colorado State University researchers evaluated the use of diagnostic real-time reverse transcription polymerase chain reaction (rrt-PCR) and reverse transcription droplet digital PCR (rt-ddPCR) data for predicting viral whole genome sequencing success. Researchers estimated the probability of observing a complete viral whole genome sequence from uncultured virus samples using both rrt-PCR and rt-ddPCR. Both methods showed similar results, and PCR thresholds were identified that resulted in high (0.95), medium (0.50–0.75), and low (0.25) probabilities of recovering full genome sequences. This approach could streamline avian influenza virus diagnostics by allowing researchers to identify robust samples to sequence that do not need virus cultures, saving time and money and reducing bias.

Contact: Toni Piaggio

- **DNA Persistence in Predator Saliva on Carcasses.** WS Operations personnel and WS NWRC geneticists have been investigating new uses for non-invasive DNA sampling (i.e., collection of hair, scat, and saliva) in wildlife damage management. Wildlife managers have used DNA samples from saliva in depredation investigations to identify the species responsible for killing livestock or endangered wildlife, but the accuracy of such samples can be affected by low DNA quality and quantity. To improve salivary DNA sample collection strategies, NWRC geneticists collaborated with the NWRC Utah field station and the non-profit Wildlife Science Center in Minnesota to investigate differences in coyote, wolf, and mountain lion salivary DNA deposits and degradation on cattle and sheep carcasses.

  Findings showed that wolf salivary DNA was the most abundant and readily obtained of the three predator species. Researchers note that DNA should be collected within the first 12 hours of deposition. After 24 hours, the DNA degrades so much that there is about a 50-percent chance of identifying the animal's genetic signature. However, this problem can be overcome by taking more samples. Findings also showed that swabbing the hide for DNA in the laboratory rather than in field settings also led to better results. These results aided in the development of new WS protocols for collecting DNA samples from depredated carcasses.

  Contact: Toni Piaggio

DNA samples from saliva on carcasses have been used in depredation investigations to identify the species responsible for killing livestock.
Photo: USDA, Wildlife Services

- **Identifying Elusive Species From Feces.** Feces are a data-rich genetic resource but are often degraded and commingled with nontarget DNA from microbes, parasites, and dietary items. NWRC and U.S. Army geneticists designed and tested new DNA assays for identifying multiple bat species and sex using bat guano (feces). These assays allow for identifying other elusive wildlife species from feces as well. Researchers also validated previously published assays that can be used with guano samples to obtain the species and sex data. Results showed that guano-derived DNA can be used successfully to (1) identify nearly all U.S. and Canadian bats at the species level or to one of three *Myotis* species clusters and (2) identify the sex of at least 23 U.S. and Canadian bat species. These findings significantly enhance the power of noninvasive sampling and genetic analysis for research, management, and conservation of elusive wildlife species.

  Contact: Toni Piaggio

- **Using Chemical Cues To Trap Invasive Lizards.** Invasive black and white Argentine tegus (*Salvator merianae*) are well established in southern parts of Florida and have been reported in Georgia and South Carolina. They eat plants and animals, but can be especially problematic for small native wildlife, ground-nesting birds, and burrowing animals. Researchers at the NWRC Florida field station, in cooperation with James Madison University, examined the importance of chemosensory cues (e.g., taste and smell) in tegus and how behavior, such as scent trailing, might be used to bolster management of this invasive species. Scent trailing is the ability to find and follow a chemical odor left in passing by another animal.

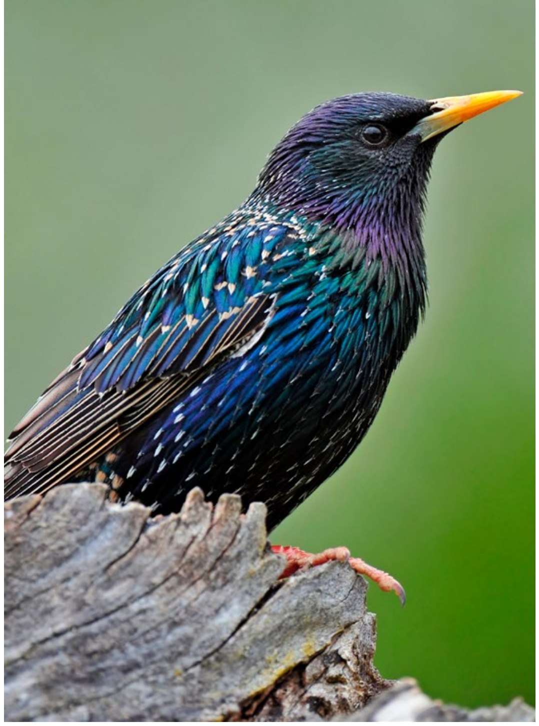
Researchers at the NWRC Florida field station, in cooperation with James Madison University, examined the importance of chemosensory cues (e.g., taste and smell) in tegus and how behavior, such as scent trailing, might be used to bolster management of this invasive species.

Graphic: James Madison University, Isabella Bukovich

  A study with captive tegus showed that females track male scent trails during the breeding season, and efforts are now underway to develop and test a pheromone-based scent lure to help trap the lizards. Pheromones are a chemical substance produced and released by an animal that triggers a social response in members of the same species. Because breeding female tegus are the drivers of this species' populations, researchers note that identifying and developing a lure could reduce populations by more efficiently removing breeding females from the landscape.

  Contact: Bryan Kluever

- **Tracking Bird Movements Using Feather Isotopes.** Understanding the origin and movement of introduced birds can aid in damage management. NWRC and University of Western Ontario researchers measured stable isotopes in feathers to infer molt origins and interstate movements of European starlings in North America. Stable isotope analysis is based on the principle



Stable isotopes found in the feathers of European starlings were used to predict where the birds last molted and their subsequent movements.
Photo: Adobe Stock

"you are what you eat." Different environments are characterized by the presence of different isotopes (versions of a chemical element). These can be incorporated into an animal's tissues through their diet. Using this technique, researchers analyzed stable hydrogen (δ^2H), carbon (δ^{13}C), and nitrogen (δ^{15}N) isotope ratios in European starling feathers collected in winter from dairies and feedlots throughout the United States.

Results showed that starlings from dairies and feedlots generally west of the Mississippi River had molt origins in their collection State or the State adjacent to their collection State. In contrast, starlings collected generally east of the Mississippi River had molt origins from more distant locations (i.e., not their collection State or the State adjacent to their collection State). Overall, only about 40 percent of the starlings collected were assigned to their collection State or to the State adjacent to their collection State, indicating that starlings have high dispersal rates. In fact, 88 percent of juvenile starlings were assigned to States other than their collection State. Researchers hypothesize this is likely the result of the young birds' initial dispersal from hatching sites. This study included an unprecedented sample of feather isotopes from European starlings throughout the United States. The results show how such feather isoscapes (geologic maps of isotope distributions) can predict molt origin and, potentially, interstate movements of European starlings—offering a useful tool for ecological and bird management investigations.

Contact: Scott Werner

Disease Diagnostics, Surveillance, Risk Assessment, and Management

- **European Starlings and Spread of Antimicrobial-Resistant *E. coli* in Feedlots.** To better understand the role wildlife play in spreading and maintaining antimicrobial-resistant bacteria in cattle feedlots, NWRC, University of Wyoming, and The Ohio State University researchers collected antimicrobial-resistant bacteria from fecal samples of invasive European starlings and cattle from 35 feedlots in 5 States. The researchers then used a suite of techniques to profile specific types of priority antimicrobial-resistant *E. coli* and assess how starling management could reduce the burden of these antimicrobial-resistant bacteria in cattle.

  For the starlings sampled, the prevalence of fluoroquinolone and third-generation cephalosporin-resistant *E. coli* was 10 percent and 4 percent, respectively. Multidrug resistance was common in the *E. coli* isolates collected, with the majority displaying resistance to six or more classes of antibiotics. Genetic assessments of bacterial whole genomes found highly similar isolates with antimicrobial resistance in starlings from feedlots separated by more than 93 miles, suggesting that starlings play a role in the interstate movement of specific bacteria with priority antimicrobial resistances. Researchers also found that as the number of birds increased at a particular feedlot, the amount of cattle fecal shedding of fluoroquinolone-resistant *E. coli* increased as well. Targeted control of starlings using DRC-1339 (an avian pesticide) effectively reduced the number of birds on the feedlots by approximately 70 percent after 1 month; however, it did not result in a lower prevalence of fluoroquinolone-resistant *E. coli* in cattle feces at the time of resampling.

Future efforts will focus on the impact of more intensive starling control and extended monitoring of fluoroquinolone-resistant *E. coli* in cattle feces. These efforts will help establish definitively whether starling control can reduce the burden of antimicrobial resistance in livestock production.

Contact: Jeff Chandler

- **Gulls and Colistin-Resistant *E. coli*.** Disease experts have long suspected that gulls may serve as reservoirs for antimicrobial-resistant bacteria, given the birds' wide-ranging movements, use of human waste sites and livestock feed, and propensity to spread pathogens. Of particular concern is resistance to colistin, a drug of last resort in patients infected with pathogenic bacteria resistant to multiple antibiotics. To learn if gulls can carry and spread the gene (*mcr-1*) that causes resistance to colistin in bacteria, NWRC, U.S. Geological Survey, and international researchers inoculated and housed 11 ring-billed gulls (*Larus delawarensis*) with two strains of *mcr-1* positive *E. coli* at the NWRC animal facilities in Colorado. Five other birds were kept as contact controls, meaning they were not inoculated but shared a common space with those that were. Over about a month, researchers collected 296 fecal, aggregated fecal, cloacal, and water samples from the birds and their enclosure. Approximately 9 percent of the samples tested positive for *mcr-1 E. coli.* Half of the inoculated birds and one contact control bird shed the bacteria. The birds shed the bacteria in their feces for

NWRC research demonstrates that ring-billed gulls can carry and spread antimicrobial-resistant bacteria.
Photo: Adobe Stock

approximately 16 days, and it was detected in their enclosure for up to 29 days.

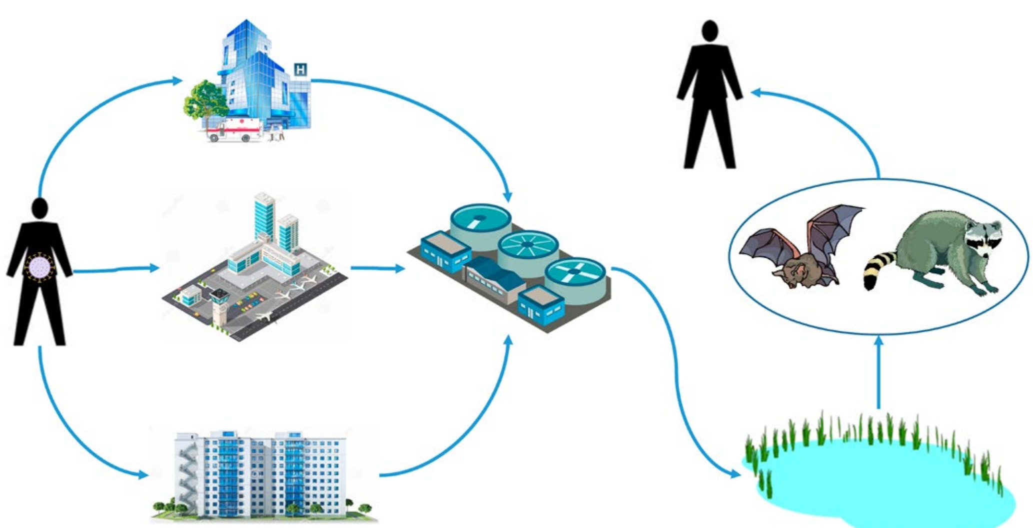
This study provides evidence that ring-billed gulls can spread colistin resistance through environmental pathways. Researchers conclude that gulls may serve as useful sentinels for *mcr-1* and other forms of colistin resistance in the environment. This finding supports the need for surveillance and management of gull colonies in certain areas where human health and safety issues are a concern.

Contact: Alan Franklin

- **Improving Estimates of Disease Infection Risk.** Detecting and anticipating when animals or people may be at a higher risk of disease infection helps mitigate disease impacts. However, it can be difficult to estimate seasonal infection risk in wildlife populations; disease surveillance often relies on antibody detection, which may not indicate current infection. New analysis methods can estimate how long ago an animal was infected by estimating the level of antibodies in a sample, but they do not account for the opportunistic or uneven sampling often associated with such surveillance data. To improve these estimates, NWRC, Colorado State University, and University of Missouri researchers used survival analysis to infer the true incidence of infection. Survival analysis is a branch of statistics used to determine the expected duration of time until an event, such as when infection happens. When researchers accounted for the uneven nature and timing of serology sampling using survival analysis, the estimates of seasonal infection risk improved. This new framework is widely applicable for estimating seasonal infection risk from antibody-based surveillance data in people, wildlife, and livestock.

  Contact: Kim Pepin

- **Conceptual Model of SARS-CoV-2 Spillover into Wild Animal Hosts.** The recent outbreak of a novel coronavirus (SARS-CoV-2), which causes COVID-19, is suspected to have a wildlife origin. With the global spread of the virus among people, the virus has the potential to spill over from infected people to native wildlife that could then serve as new reservoir hosts for the virus. In this way, the virus may become entrenched in new locations and available for future outbreaks. NWRC researchers



NWRC researchers hypothesize that SARS-CoV-2 (the virus that causes COVID-19) could spill over into new wildlife hosts through a city's wastewater treatment system. Infected people shed the virus in their feces. This shedding could lead to contamination of natural aquatic environments near treatment facilities visited by raccoons, bats, and other wildlife.

Graphic: USDA, Wildlife Services

hypothesized that SARS-CoV-2 could spill over into new wildlife hosts through a city's wastewater treatment system. Infected people shed the virus in their feces. This shedding could lead to contamination of natural aquatic environments near treatment facilities visited by raccoons, bats, and other wildlife. Spillback of SARS-CoV-2 from the new wildlife hosts back to people is also possible. Researchers recommend an enhanced surveillance program that involves: (1) identifying "hotspot" locations with high human caseloads of COVID-19, (2) identifying areas downstream of wastewater treatment release sites, and (3) sampling for virus antibodies and viral presence in targeted wildlife species, such as raccoons and bats, in these areas.

Contact: Alan Franklin

- **Possible Impacts of SARS-CoV-2 on North American Bats.** The COVID-19 pandemic, caused by the novel coronavirus SARS-CoV-2, highlights the substantial public health, economic, and societal consequences of virus spillover from a wildlife reservoir. The establishment of new wildlife reservoirs for SARS-CoV-2 would further complicate public health control measures, wildlife health, and conservation. Given the likely bat origin of SARS-CoV-2 and related beta-coronaviruses (β-CoVs), free-ranging bats are a key group of concern for spillover from people back to wildlife. An international team of researchers from multiple organizations and universities (including NWRC) reviewed the diversity and natural host range of β-CoVs in bats and examined the risk of humans inadvertently infecting free-ranging bats with SARS-CoV-2.

Findings show more than 40 species of temperate-zone North American bats could be susceptible to SARS-CoV-2 infection. Researchers recommend One Health strategies to continue important management and research efforts while avoiding the potential health and conservation impacts of SARS-CoV-2 "spilling back" into free-ranging bat populations in North America. The One Health approach highlights the interconnection among humans, animals, and the environment. It encourages experts from multiple disciplines to work together locally, nationally, and globally to help achieve the best health for people, animals, and the environment.

Contact: Amy Gilbert

- **Oral Vaccine for Fatal Devil Facial Tumor in Tasmanian Devils.** The Tasmanian devil (*Sarcophilus harrisii*) is the largest carnivorous marsupial. Since 1996, its population has declined by 77 percent, mainly due to a transmissible cancer known as devil facial tumor (DFT1) disease. In 2014, a second transmissible devil facial tumor (DFT2) was discovered. DFT1 and DFT2 are nearly 100-percent fatal. Australian scientists partnered with NWRC to evaluate a potential rabies-style oral bait vaccine (OBV) program for DFTs. Rabies OBVs have a long safety record. The WS National Rabies Management Program, which works closely with WS NWRC researchers, has been using an OBV approach to control the spread of rabies in terrestrial wildlife in the United States since 1997. After evaluating the benefits and limitations of various vaccine options, the team recommended the development and regional distribution of a vaccine to prevent DFT2 from spreading. The platform could be modified in the future for DFT1 and other disease threats. The vaccine option that balances safety with the greatest likelihood

Australian scientists partnered with NWRC to evaluate a potential rabies-style oral bait vaccine program to combat the deadly devil facial tumor disease in Tasmanian devils.
Photo: University of Tasmania, Andy Flies

of success is an oncolytic viral vector (a virus that infects and breaks down cancer cells but not normal cells) that expresses DFT-specific antigens and is packaged inside an OBV capsule attractive to Tasmanian devils.

Contact: Amy Gilbert

- **Mongoose ORV Bait Uptake by Nontarget Species.** The small Indian mongoose is a wildlife reservoir for rabies virus on several Caribbean islands. Oral rabies vaccination (ORV) has been suggested to prevent the spread of rabies in mongooses, but there are limited data on the longevity and use of ORV baits in tropical climates. NWRC researchers partnered with Ross University (St. Kitts) and Ceva Sante Animale (Germany) to compare disappearance rates of an egg-flavored placebo bait block versus canned tuna placed at 45 bait stations on the island of St. Kitts, West Indies. For bait blocks, the researchers also assessed if season, habitat, and time of day (i.e., day versus night) influenced the disappearance rate.

  Across all sites and bait stations, control baits were removed faster than bait blocks. Within 36 hours, over 90 percent of all baits had disappeared. For bait blocks only, the disappearance rate was higher during the dry season and in the dry forest habitat compared to the other habitats. There was no difference between day and nighttime disappearance rates. While the exact species that ate the baits remain uncertain, researchers note that mongooses readily removed bait blocks, along with non-native mammals (e.g., dogs and cats) and land crabs in coastline and shoreline habitats near water. Findings indicate that bait blocks may be suitable for use as an external bait matrix for ORV baits in tropical habitats.

  Contact: Are Berentsen

- **Rat Lungworm in Invasive Frogs.** The rat lungworm (*Angiostrongylus cantonensis*) has emerged as an important human and animal health concern in Hawaii. The parasitic worm is typically found in rats but can cause severe gastrointestinal or central nervous system diseases in people. Infected rats can pass larvae of the worm in their feces to intermediate hosts, such as snails, slugs, and other animals. People can become infected if they accidentally or intentionally eat raw or undercooked plants not properly rinsed of snails and their larvae or infected animals. NWRC and University of Hawaii researchers investigated the occurrence of rat lungworm infections in other potential intermediate host species in Hawaii to provide information on how they might be involved in disease transmission.

Researchers confirmed the presence of rat lungworm in three invasive amphibians in Hawaii: coqui frogs (*Eleutherodactylus coqui*), Cuban greenhouse frogs (*Eleutherodactylus planirostris*), and cane toads (*Rhinella marina*). Approximately 87 percent of the coqui frogs sampled were infected with the parasite. The parasite was also found in centipedes (*Scolopendra subspinipes*). The findings suggest that these species may aid in spreading the parasite in Hawaii and to other locations, such as Guam and the continental United States.

Contact: Shane Siers

- **African Swine Fever in Wild Boar.** Although not found in the United States, African swine fever (ASF) is a highly infectious swine disease with devastating consequences for the domestic swine industry and food security globally. The virus is known to spread through host-to-host contact; contact with infected carcasses; meat products; shoes, clothing and other materials; aerosols; the environment; or through tick vectors. NWRC and Colorado State University researchers and partners in Poland and the Czech Republic modeled ASF virus transmission in wild boar to estimate what proportion of carcass-based transmission is contributing to the persistence of ASF in Eastern European wild boar. The model showed that between 53 and 66 percent of transmission events were carcass-based (i.e., ASF virus was transmitted through contact between a live host with a contaminated carcass). To control ASF virus in wild boar, researchers recommend that wild boar control programs include intensive surveillance and the removal of dead wild boar carcasses to prevent pathogen spread, especially as wild boar populations reach low densities.

  Contact: Kim Pepin

Approximately 87 percent of invasive coqui frogs sampled in Hawaii were infected with rat lungworm, a parasite that can cause severe gastrointestinal or central nervous system diseases in people.
Photo: Adobe Stock

Wildlife Damage Assessments

- **Feral Swine Impacts to Corn and Peanuts.** Feral swine cause an estimated $61 million in damages to corn and $40 million in damages to peanuts across 11 States each year. Yet, little is known about the timing of damage and the extent to which local habitat characteristics might help predict feral swine damage to these crops. NWRC and University of Georgia researchers conducted surveys throughout the growing season for 29 corn and 41 peanut fields in South Carolina to determine which crop growth stages were the most impacted by feral swine. Damage to corn peaked shortly after planting during

Feral swine cause an estimated $61 million in damages to corn and $40 million in damages to peanuts (pictured) annually across 11 States in the United States.
Photo: USDA, Wildlife Services

the seedling stage and resumed during the mature stages. Peanut damage was almost exclusively limited to the seedling stage. Landscape models for both crops also indicated the amount of forested and wetland areas surrounding crop fields correlated with an increase in feral swine damage.

Based on these findings, researchers recommend that management efforts to limit feral swine damage in these crops be conducted shortly before planting. The researchers also note that feral swine damage may be most severe near areas of preferred habitat.

Contact: Kurt VerCauteren

- **Understanding Crop Use and Preference of Feral Swine.** Feral swine cause significant crop damage across the United States, but how and why they use specific crops is unknown. To predict how the availability of crops and natural forage (i.e., grasses, acorns, bulbs/tubers, mushrooms, and animal matter) might influence crop visitation by feral swine, NWRC researchers and multiple university and Federal partners compiled data from 24 previous studies involving 326 feral swine in California, Florida, Georgia, Louisiana, Missouri, South Carolina, and Texas. Data from global positioning system (GPS) collars tracked the animals' movements and time spent in crops. Researchers used mechanistic movement models and resource selection theory to analyze the data, along with USDA annual crop records.

Results showed that feral swine crop use increased exponentially with crop availability.[1] Crop visitation rates were influenced by feral swine sex, crop type, abundance of natural forage, and the distance between the feral swine's core home range and the crop. Fruit and nut crops were visited the most and were preferred over other crops when available. Crop preferences by feral swine varied by State, but tended to include double crops (e.g., winter wheat plus another cereal crop), corn, sorghum, nuts, and fruit.

The information helps managers, landowners, and producers better allocate their damage management resources. It will also aid in the development of more efficient tools and strategies for managing feral swine damage.

Contact: Kim Pepin

[1] Researchers defined "crop availability" as the proportion of the animals' home range that encompassed a particular crop during each crop growing season.

- **Feral Swine Impacts to Soil and Vegetation.** Using location data from radio-collared feral swine, NWRC and Michigan State University researchers assessed the short-term effects of feral swine on native plants and soil across four counties in the central Lower Peninsula of Michigan. Feral swine damage forest floors through their wallowing and rooting. Over a span of about 2 years, researchers discovered that plots disturbed by feral swine showed less cover of native herbaceous plants and a lower diversity of plant species than non-disturbed plots. Concentrations of magnesium and ammonium were also significantly lower in the soil of disturbed plots, suggesting that soil disturbances accelerated leaching of macronutrients, potentially altering nitrogen transformation processes. Findings did not show evidence that feral swine disturbance helped establish and spread exotic plants; however, the prevalence of exotic plants was low, and effects of feral swine disturbance may be more pronounced in areas heavily dominated by exotic plants. Researchers conclude that excluding feral swine from rare or endemic plant communities helps to protect native plants and soil chemistry.

  Contact: Kurt VerCauteren

- **Feral Swine Predation on Wild Turkeys.** Feral swine eat native wildlife, particularly ground-nesting birds, eggs, and chicks during the nesting season. In areas inhabited by wild turkeys (*Meleagris gallopavo*), nest destruction caused by feral swine may affect turkey populations. To determine whether feral swine actively seek ground-nesting bird nests or eat them opportunistically, NWRC and Texas A&M University researchers examined the movements of feral swine relative to artificial wild turkey nests placed at moderate and high densities in areas in south-central Texas during the turkey nesting season. The researchers found no evidence that feral swine learned to seek out and eat wild turkey nests during nesting periods or when nest density increased. Feral swine did not alter their behavior to exploit turkey nests as nests became more available. Despite feral swine being important nest predators, depredation appeared to be opportunistic. Researchers note that protecting the

Feral swine damage forest floors through their wallowing and rooting. Over a span of about 2 years, NWRC researchers discovered that areas disturbed by feral swine had fewer native herbaceous plants and lower plant diversity.
Photo: USDA, Wildlife Services

Feral swine eat native wildlife, particularly ground-nesting birds, eggs, and chicks during the nesting season.
Photo: Texas A&M University, Heather Sanders

reproductive success of wild turkeys will require reducing feral swine densities in nesting habitats before the nesting season.

Contact: Nathan Snow

- **Habitat Characteristics and Fish-Eating Bird Use of Catfish Ponds.** Double-crested cormorants (*Phalacrocorax auratus*), great blue herons, and great egrets commonly feed on fish at aquaculture facilities in the Mississippi Delta. Past studies estimate that catfish depredation by these species costs producers millions of dollars each year. To better understand how these species select for certain ponds over others at aquaculture facilities, NWRC and Mississippi State University researchers gathered and analyzed data on bird use and characteristics of catfish ponds, such as pond size, catfish species, single or multi-batch production method, stocking level, and surrounding habitat.

  Results showed larger ponds were more likely to have fish-eating birds than smaller ponds. Cormorant abundance increased with the abundance of catfish in a pond and as pond distance increased from forested areas and areas with more human activity. Ponds with diseased catfish were more likely to be used by foraging herons and egrets. In general, cormorants and egrets were more likely to use ponds on the periphery of pond clusters. Many of the pond selection relationships were species-specific, thus researchers note specific management actions for reducing bird presence at catfish ponds will depend on the targeted species. Information such as this has the potential to increase bird

To better understand how cormorants, herons (pictured), and egrets select for certain ponds over others at aquaculture facilities, NWRC and Mississippi State University researchers gathered and analyzed data on bird use and characteristics of catfish ponds, such as pond size, catfish species, single or multi-batch production method, stocking level, and surrounding habitat.
Photo: Adobe Stock

NWRC researchers hypothesize that scaup increasingly exploit fish on aquaculture facilities in colder winters, perhaps because of the birds' increased energy demands, prey availability and ease of capture, or some combination of these factors.
Photo: Adobe Stock

harassment efficiency and inform future stocking decisions.

Contact: Brian Dorr

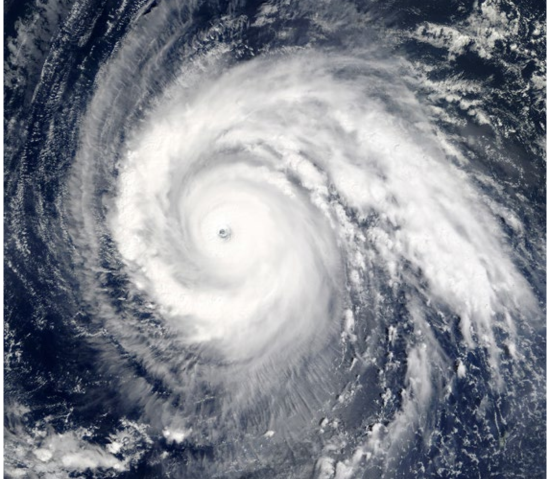
- **Diets of Scaup at Fish Farms.** Lesser scaup (*Aythya affinis*) and greater scaup (*Aythya marila*) are two of the most numerous and widespread diving ducks in North America. Although not typically associated with eating fish, both species have been reported eating large quantities of bait- and sport fish produced on Arkansas commercial aquaculture facilities. NWRC and university researchers collected lesser scaup and greater scaup foraging on golden shriner (*Notemigonus crysoleucas*), fathead minnow (*Pimephales promelas*), goldfish (*Carassius auratus*), sunfish (*Lepomis* spp.), and other sport fish ponds. The researchers compared diet compositions of the two duck species, as well as differences in foraging behavior based on temperature and pond type.

  Results showed that diets of both species contained mostly animal prey, accounting for 84 percent in lesser scaup and 100 percent in greater scaup. Chironomidae (non-biting midges) was the most common food detected in both species' diets. Fish consumption by scaup was associated with winter temperatures. In warmer months, a small proportion of scaup ate fish; in the colder months, more fish were eaten by scaup. Researchers hypothesize that scaup increasingly exploited fish in colder winters, perhaps because of the birds' increased energy demands, prey availability, and ease of capture or some combination of these factors. This information can help baitfish producers more efficiently manage scaup depredation.

  Contact: Brian Dorr

- **Estimating the Cost of Wildlife Strikes: The Relationship Between Profitability and Disclosure.** Between 1990 and 2018, wildlife collisions with airplanes (wildlife strikes) resulted in $154 million in direct repair costs annually. In 1995, the Federal Aviation Administration (FAA) collaborated with WS to obtain more information about the magnitude and nature of wildlife strikes, ultimately creating the National Wildlife Strike Database. Reporting wildlife strikes to the database is not mandatory for airlines, but it is strongly encouraged by the FAA.

  In a recent study, NWRC economists investigated how changes in airline market structure and competition may influence voluntary reporting and subsequent damage estimates. Over the past decade, the U.S. airline industry has consolidated through several mergers, making it less competitive. Results showed that the probability of an airline disclosing direct repair costs after a wildlife strike is linked to market competition and profitability. The more profitable and competitive an airline, the less likely it is to voluntarily disclose costs. Researchers note that, to boost reporting, policymakers may want to restrict public access to National



Islands hit by large storms, such as hurricanes, can experience spikes in rodent populations, which may require temporary or long-term adjustments in invasive species management strategies.
Photo: Adobe Stock

Wildlife Strike Database information on damage costs. Limiting the amount of information shared with airline competitors may remove potential concerns associated with disclosure.

Contact: Aaron Anderson

- **Hurricanes and the Spread of Invasive Species.** In September 2017, Hurricane Irma and Hurricane Maria—both Category 5 storms—struck the island of St. Croix in the Caribbean. Afterward, NWRC worked with its Federal and university partners to determine how the severe storms affected the island's invasive small mammal populations. St. Croix's invasive species (house mice, black rats, and mongooses) are known to threaten endangered St. Croix ground lizards and nesting sea turtles. Hurricanes and other large storms can shift rodent populations, often causing a spike in their numbers and a need to adjust temporary or long-term management strategies. Using footprint-tracking tunnels and other surveillance tools on St. Croix and smaller islands nearby, the research team collected new sampling data, compared it to data from before the storms, and quickly determined where and to what extent the invasive species populations shifted.

  Sampling data of the small mammal community at St. Croix's Sandy Point National Wildlife Refuge showed that house mouse abundance increased after the hurricanes, rat populations appeared unchanged, and mongoose populations tended to decrease. On Buck Island Reef National Monument, sampling showed the island is still rat free, and the house mouse population (that existed before rats were eradicated from the island) is still there but more than doubled 15 months after the hurricanes. Most importantly, surveillance on Green Cay National Wildlife Refuge found that black rats invaded and established on this small island near St. Croix, probably by rafting (i.e., riding on floating debris) or swimming. As a result, the U.S. Fish and Wildlife Service partnered with WS Operations to eradicate the newly established rats from Green Cay in 2019.

  Contact: Aaron Shiels

Wildlife Management Methods and Evaluations

- **Improving Feral Swine Visitation to Bait Sites.** Management and monitoring methods for feral swine often depend on baiting programs that draw the animals into a location to be trapped or counted. To improve feral swine visitation to bait sites, it is important to understand the relationships between bait placement and feral swine movement. NWRC and University of Georgia researchers examined how ecological factors (e.g., sex, site, home range size) and baiting practices (e.g., number and spacing of bait sites) influence the probability of a bait site being visited, the amount of time until an animal first visits a bait site, and changes in an animal's movements relative to bait site locations. Results showed radio-collared feral swine in Texas and South Carolina traveled up to 0.9 miles (1.46 km) on average to reach a bait site. The distance traveled was dependent on habitat quality—feral swine in lower quality habitats traveled greater distances. Eighty percent of the feral swine first visited bait sites within 9 days

NWRC and University of Georgia researchers examined how ecological factors and baiting practices influence the probability of feral swine visiting a bait site.
Photo: USDA, Wildlife Services

after bait deployment, and they visited earlier when their home range size was larger. There was no difference between the sexes in how soon or how far feral swine traveled to the bait sites.

Contact: Kim Pepin

- **Factors and Costs Associated With Removing Invasive Feral Swine From Illinois.** In 2005, a newly established population of feral swine was confirmed in Fulton County, IL. From 2011 to 2016, the State partnered with WS and other Federal and local officials to eradicate the feral swine from the county. To identify important factors that helped the removal effort and evaluate the cost of removal activities, NWRC researchers examined surveillance data from camera traps at bait sites and records of feral swine removals.

  Results showed that feral swine used bait sites most during the night and on days with lower daily maximum temperatures. Increased removals of feral swine coincided with periods of cold weather. Researchers also identified that fidelity and time spent at bait sites by feral swine was not influenced by increasing removals of swine. Finally, the costs to remove the first 99 percent of the feral swine averaged $50 per animal and involved approximately 7 effort-hours per swine. Costs for removing the last 1 percent were much higher ($4,200 per animal) and averaged 123 effort-hours per animal removed. In short, the most efficient time to remove feral swine using bait sites was during periods of environmental stress. These results inform programs working to remove newly established populations of feral swine, and ultimately prevent them from spreading.

  Contact: Justin Fischer

- **Waste Management Facilities and Bird Strike Hazards.** Bird collisions with aircraft cause serious safety hazards and economic losses to the aviation industry. Land uses near airports, such as waste transfer stations and landfills, can attract hazardous wildlife. Identifying and managing land-use practices is an important part of an integrated approach to reduce wildlife-aircraft collisions. NWRC researchers conducted a 3-year study to see if having a Wildlife Hazard Mitigation Program would influence bird use of a waste transfer station near LaGuardia Airport in New York City. The researchers gathered data on the number, species, and activities (e.g., feeding, loafing, nesting) of birds at the station during three phases: (1) no wildlife management actions at a non-operating facility, (2) active wildlife management at a non-operating facility, and (3) active wildlife management at a fully operating facility. Wildlife management actions included processing and containing trash inside the fully enclosed facility, inspecting and cleaning areas surrounding

Identifying and addressing land use near airports, such as waste transfer stations and landfills, that might attract wildlife is important to reduce wildlife-aircraft collisions.
Photo: USDA, Brian Washburn

the facility multiple times per day, posting "no feeding wildlife" signs, removing standing water, installing anti-perching devices, dispersing birds with pyrotechnics, trapping and shooting of some birds to reinforce nonlethal techniques, and removing nests.

More than 7,500 birds comprising 52 species were observed during the bird surveys. Of the species considered a "very high" hazard to aircraft due to their size and flocking behavior, researchers observed an 82- and 85-percent decline in their abundance during phases 2 and 3, respectively. Results showed that overall bird abundance decreased with wildlife management actions both before and when the facility was operational, thereby reducing the risk of bird strikes with aircraft at LaGuardia Airport. In a similar study, NWRC researchers investigated the effect of municipal solid waste facilities and landfills, landscape diversity, and human population density on the rate of bird strikes associated with nearby airports. Researchers predicted that airports surrounded by a high density of waste and landfill facilities, high human population densities, and high landscape diversity would increase the potential for damaging bird strikes. Model results, however, were inconclusive. Future efforts will look at birds' three-dimensional space use in these areas and include previously unmeasured landscape features that may be influential.

Contact: Brian Washburn and Morgan Pfeiffer

NWRC researchers tracked the movement and survival of 81 collared female black bears in Durango, CO. Results showed that bears increased their foraging within residential areas when natural foods were scarce.
Photo: Adobe Stock

- **Bear Use of Developed Areas.** When faced with habitat loss and increased human activity, wild animals often change their behaviors and movements to avoid people. Some animals, however, have learned to navigate human-developed landscapes and take advantage of human resources within residential areas. To better understand how black bear use of residential areas impacts bear populations, NWRC researchers tracked the movements and survival of 81 collared female black bears in Durango, CO. Results showed that bears increased their foraging within residential areas when natural foods were scarce. This increased use was associated with increased body fat and reproductive rates, but also resulted in reduced cub and adult bear survival. Researchers included the data in a population matrix model, which showed increased bear use of residential areas led to population declines due to human-caused mortality (i.e., vehicle collisions, conflict removal). These results emphasize the need to consider the impact to black bear populations when promoting coexistence of people and black bears on shared landscapes.

Contact: Stewart Breck

- **Public Perspectives of Wolf Reintroduction in Colorado.** Predator management and reintroduction are some of the most contentious conservation issues in the American West. In Colorado, a 2020 citizen ballot initiative to reintroduce gray wolves led to polarization and conflict among multiple stakeholder and interest groups. Colorado State University and NWRC researchers used an online survey of 734 Coloradans from different regions across the State to examine public beliefs and attitudes about wolf reintroduction and various wolf management options. Findings suggest a high degree of social tolerance or desire for wolf reintroduction in Colorado across geographies, stakeholder groups, and demographics. However, researchers also found that a portion of the public believes wolves would negatively impact their livelihoods, mainly because of concerns over the safety of people and pets, loss of hunting opportunities, and potential wolf predation on livestock.

  Researchers also conducted a content analysis of media coverage on potential wolf reintroduction in 10 major daily Colorado newspapers. They found that media coverage has focused only on a few of the many potential impacts of wolf reintroduction identified among the public and emphasized more negative than positive impacts. Researchers recommend that decision makers account for this diversity of perspectives in future decisions and conduct public outreach on the likely impacts of wolf reintroductions.

  Contact: Stewart Breck

- **Effects of Oil Exposure on Bird Feather Structure and Thermoregulation.** Impacts of oil spills on birds are far-reaching. While media attention often focuses on the lethal impacts, sublethal effects and the impacts of rehabilitation receive less attention. NWRC and Colorado State University researchers described the effects of moderate external oiling and subsequent rehabilitation on the feather structure and thermoregulation of captive ring-billed gulls. Thirty ring-billed gulls were randomly assigned to one of three experimental groups: (1) controls (not oiled or rehabilitated); (2) rehabilitated birds (externally oiled, rehabilitated by washing); or (3) oiled birds (externally oiled, not rehabilitated). Birds were externally oiled, and data collected to investigate feather structure (i.e., amount of clumping) and thermoregulatory ability (i.e., internal body temperature and external surface temperature). Pristine feather condition is critical for birds to control their body temperatures.

  The researchers found that feather clumping after moderate levels of oiling was evident for at least a month. Washing the birds—as was done for rehabilitation—reduced clumping to normal levels within 3 weeks. Internal body temperatures did not differ among the groups, suggesting that birds maintained thermoregulatory stability despite moderate external oiling. External temperatures for rehabilitated birds did not differ from controls within a week of rehabilitation. Overall, rehabilitation procedures were effective and washed birds were in better condition than non-rehabilitated, oiled

Pristine feather condition is critical for birds to control their body temperatures. NWRC and Colorado State University researchers studied the effects of moderate external oiling and subsequent rehabilitation on the feather structure and thermoregulation of captive ring-billed gulls.
Photo: USDA, Susan Shriner

birds. These findings prove the benefits of rehabilitation for moderately oiled birds.

Contact: Katherine Horak

- **Animal Behavior and the Effectiveness of Management Tools.** Understanding the foraging behavior of invasive species is crucial to manage them effectively. Specific traits and behaviors related to size and body condition may result in some individuals being missed during eradication efforts. To evaluate the effect of individual traits and behaviors on the efficacy of invasive species control, NWRC, U.S. Geological Survey, and Dickinson College researchers monitored invasive brown tree snake populations on Guam before and after baiting with a toxicant-laden mouse bait. Results showed that snakes were more likely to be killed by toxic baits if they (1) had a lower body weight; (2) were more active leading up to a bait application (i.e., foraging more); and (3) were more often encountered on the ground. Larger, healthier snakes were encountered more in general after the bait application. Also, the number of snakes on the ground overall decreased. Larger snakes in poor condition were more likely to be encountered on the ground. These findings have direct implications for management tools designed to reach snakes in tree canopies or other areas above ground.

  Contact: Shane Siers

Wildlife Population Monitoring Methods and Evaluations

- **Wind Turbine Impacts to Bats and Birds.** Wind energy offers environmental benefits, but wind facilities can negatively impact wildlife, including birds and bats. Understanding the horizontal fall distance between the nearest turbine pole and a bird or bat carcass aids in designing effective search protocols and estimating total mortality caused by collisions with wind turbines. In a recent study, NWRC, U.S. Fish and Wildlife Service, and North Carolina State University researchers explored patterns in bird and bat carcass fall distances and species composition at wind facilities in the Northeastern United States. The researchers used publicly available data and data submitted to the U.S. Fish and Wildlife Service under scientific collecting and special purpose utility permits. Forty-four wind facilities reported 2,039 bird fatalities across 128 species, and 22 facilities reported 418 bat fatalities across 5 species.

  Results showed that carcasses of short-distance migratory birds were found farther from turbines than long-distance migratory birds. Heavier birds and bats had greater fall distances, meaning they were located farther away from the turbines. Fall distances of birds and bats collectively also increased as turbine size increased. This suggests that as turbines increase in size, a greater search radius is needed to detect carcasses. Interestingly, only a high number of bird carcasses were found near turbine bases. Researchers attribute this to collisions with turbine poles in addition to blades. This phenomenon varied across bird species, with potential implications for the accuracy of mortality estimates. Researchers note turbines may be a collision threat to birds not only because of their motion, but also because of their height.

Contact: Bryan Kluever

- **Effects of Sublethal Oil Exposure to Birds.** Thousands of birds died because of direct oiling from the 2010 Deepwater Horizon oil spill in the northern Gulf of Mexico. But, for birds that survived, the nature and extent of injuries from oil exposure was not well known. Studies show that oil, when ingested at less than acutely lethal doses, can have a wide range of adverse effects on birds, including anemia, decreased nutrient absorption, altered stress response, and decreased immune function. Understanding the effects of sublethal oil exposure on individual bird health, behavior, and potential fate helps to inform damage assessments and the overall impact of oil spills on bird populations. NWRC, U.S. Fish and Wildlife Service, and University of Wisconsin-Madison researchers calculated the potential impacts of sublethal oil exposure to wintering and breeding double-crested cormorants through the novel use of a biophysical model called Niche Mapper. Niche Mapper combines two models: a microclimate model and a generic animal model.

  Researchers used Niche Mapper to calculate the total resting metabolic heat production requirements and thermoregulatory costs of a perched cormorant for an average day each month of the year across their wintering and breeding areas in the Eastern United States. Results showed cormorants exposed to low, medium, and high sublethal amounts of oil had on average a 31-, 59-, and 76-percent predicted increase, respectively, in total resting energetic requirements (or resting metabolic rate) compared to unoiled birds. This caused an increase in the daily time spent foraging. Similar trends were seen in breeding cormorants. Researchers note these changes in metabolic rate and foraging behavior may be detrimental to a bird's ability to build fat reserves for migration and reproduction.

  Contact: Brian Dorr

Wind energy offers environmental benefits, but wind facilities can negatively impact wildlife, including birds and bats.
Photo: Adobe Stock

- **Population Structure in Double-Crested Cormorants.** Double-crested cormorants have undergone an amazing population recovery since the 1970s. Through a combination of the species' ability to adapt to human-made landscape changes (aquaculture, construction of reservoirs) to a reduction in pollution and an increase in regulatory protections, cormorants rebounded from a low of 200 nesting pairs in the 1970s to more than 115,000 nesting pairs in 2000 in the Great Lakes region alone. Their abundance has led to an increase in human-cormorant conflicts and an interest in potentially classifying and managing cormorants by subspecies.

  NWRC, Towson University, and Savannah River Ecology Laboratory researchers used samples from more than 1,700 cormorants collected across the Eastern United States to explore the effects of migratory flyways on population composition and structure. Researchers also quantified the genetic effects of population bottlenecks and determined whether individual cormorants could be successfully assigned to their natal populations based on genetics. Results showed that cormorant populations differed genetically by flyways, but there was no evidence of genetic bottlenecks and only minimal success in assigning individuals to their natal populations. Researchers concluded that the cormorants in the study were genetically diverse and weakly divided into two populations, which supports the continued management of cormorant populations by flyway.

  Contact: Brian Dorr

- **Assessing Feral Swine Populations Using Baited Cameras.** Camera traps are increasingly used to monitor wildlife populations and estimate density, abundance, and relative abundance indices. However, there is need to develop cost-effective and efficient estimation methods that can be readily and practically deployed. NWRC and several university researchers evaluated the use of 10-day baited camera trap grids spaced approximately 500 or 750 meters apart for conducting rapid population assessments (RPA) of feral swine in Florida, California, and South Carolina where swine densities and habitats varied. The researchers assessed several statistical metrics to measure changes in feral swine populations before and after removal operations or seasonally.

  Feral swine were detected within each 10-day survey, proving that the method can provide presence data, which could help wildlife managers identify recently established swine populations. The ability of RPA grids to track population trends after management removal efforts and seasonal differences in habitat use varied depending on the statistical method and number of camera traps used. Researchers concluded that RPA grids can be a useful tool to track changes in feral swine population size, evaluate the effectiveness of management actions, and monitor areas threatened by feral swine invasion.

  Contact: Kurt VerCauteren

- **Brown Tree Snake Activity Before and After Aerial Baiting.** Invasive brown tree snakes on Guam have caused severe ecological and economic damage and pose an invasion risk on other islands. Although trapping, toxicants, and hand-removal are standard brown tree snake management practices, these methods are not cost effective for controlling the snakes in the island's remote and rugged forests. In 2016, the first major field application of a helicopter-based automated aerial bait delivery system treated a 110-hectare forested plot on Guam with toxic baits at a rate of approximately 120 baits per hectare. NWRC researchers evaluated the extent and duration of the application on brown tree snakes before and after the bait drop by placing 4,420 nontoxic baits in random locations and monitoring bait removal by snakes. The amount of nontoxic bait removed by snakes was used as a proxy index of relative snake abundance in the treated plot and surrounding non-treated areas.

Over the first 30 days after the toxic bait drop, the average nontoxic bait removal rate in the treatment plot decreased by about 41 percent. There was no immediate decrease in bait removal in the nontreated reference area. Reduced snake activity was still evident in the treated area nearly 12 months after the bait drop. Results show that automated aerial bait applications can suppress brown tree snake abundance over a large area and that reinvasion by snakes from surrounding untreated habitat occurs over several months. Researchers anticipate that repeated aerial bait applications could reduce brown tree snake abundance on a landscape scale, potentially improving biosecurity and enabling the reintroduction of native birds.

Contact: Shane Siers

Registration Updates

- **Rodenticide Products for Island Conservation.** In their roles on the WS Island Restoration Committee and Pesticide Coordination Subcommittee, the NWRC Registration Unit identified and developed third-party registration proposals for promising new rodenticide products for island conservation use to control invasive rats and mice. The products are a bromethalin block and a bromethalin place pack, produced by Bell Labs. The applications were submitted to the U.S. Environmental Protection Agency (EPA) in August 2020. An EPA decision is expected by November 2021. If accepted, these new registrations will give island conservation managers additional bait and active ingredient options and general use products that both Federal and State wildlife management agencies can purchase. The proposed labels will also allow for new hand-baiting methods, including string lines and bolas for canopy baiting and tethered floating bait stations for areas periodically inundated with water.

  Additionally, EPA accepted label amendments for APHIS' three existing conservation rodenticide labels (Diphacinone-50 Conservation, Brodifacoum-25D Conservation, and Brodifacoum-25W Conservation) in November 2019. The proposed labels revised the hand-baiting application allowances. The amended labels are expected to improve product application effectiveness and ease-of-use on the ground, helping Federal and State wildlife

NWRC researchers evaluated the extent and duration of an aerial bait application on brown tree snakes.
Photo: USDA, Shane Siers

managers in their rodent control work on U.S. islands.

Contact: Jeanette O'Hare

- **GonaCon for Prairie Dog Management.** The NWRC Registration Unit submitted a pesticide registration application to EPA in June 2020 for "GonaCon–Prairie Dogs," an immunocontraceptive vaccine to reduce fertility in female black-tailed prairie dogs (*Cynomys ludovicianus*). An EPA registration decision is due no later than October 2021. If approved, WS Operations in States such as Colorado and New Mexico will have another nonlethal tool for prairie dog management at nonagricultural-use sites, such as natural areas, campgrounds, and airports.

  Contact: Jeanette O'Hare

- **Sodium Nitrite Bait for Feral Swine.** The NWRC Registration Unit worked closely with the NWRC Feral Swine Project to address EPA regulatory requirements for the ongoing development of a sodium nitrite-based pesticide to lethally remove feral swine. In October 2020, NWRC prepared and submitted an experimental use permit (EUP) application to the EPA for a large-scale field study of a sodium nitrite-based bait called HOGGONE 2. If successful, results from the EUP field study and other studies on the pesticide's active ingredient and formulation will support the registration of this new tool to manage invasive feral swine in the United States.

  Contact: Jeanette O'Hare

Technology Transfer

- **Patents, Licenses, and New Inventions.** In fiscal year 2020, NWRC scientists were awarded two U.S. patents and two foreign patents. This included three resulting from the Center's collaboration with Arkion Life Sciences to develop chemical repellents for managing wildlife damage in crops and other locations (U.S. Patent and Trademark Office [USPTO] #10,638,745, South Africa #2017/01198, and Colombia #NC2017/0001590) and one patent for a novel formulation of a contraceptive vaccine for pest animal management (USPTO #10,434,1717). NWRC scientists also submitted three provisional patent applications and two non-provisional patent applications.

  Contact: John Eisemann

- **Technology Transfer Agreements.** WS forms research and product development partnerships to promote the development of tools and techniques for use in wildlife damage management. Collaborations often are formalized through confidentiality, material transfer, and other intellectual property agreements. In fiscal year 2020, NWRC entered into 10 Confidentiality Agreements, 12 Material Transfer Agreements, 7 Material Transfer Research Agreements, 2 Memorandum of Understanding, 3 Cooperative Research and Development Agreements, and 3 Invention Disclosures.

  Contact: John Eisemann

Awards

- **2020 NWRC Publication Award.** Each year, the NWRC Publication Awards Committee, composed of NWRC scientists, reviews over 125 publications generated by their NWRC colleagues. The resulting peer-recognized award honors outstanding contributions to science and wildlife damage management. In 2020, the Committee presented the award to Amy Davis, Amy Gilbert, Tatiana Xifara, and Kim Pepin for their work on the paper "Not all surveillance data are created equal—A multi-method dynamic occupancy approach to determine rabies elimination from wildlife" (*Journal of Applied Ecology* 56:2551–2561).

This publication arose from a multi-disciplinary collaboration between the NWRC, the National Rabies Management Program (NRMP), the U.S. Centers for Disease Control and Prevention, and Colorado State University. The authors used long-term rabies management data to estimate and measure the impacts of oral rabies vaccination toward the elimination of this pathogen in the region encompassing Ohio, West Virginia, and Pennsylvania. This new tool, which used multiple surveillance methods (targeted and convenience-based) in conjunction with dynamic occupancy analyses, can inform management decisions by providing an understanding of the ecological factors that drive rabies occurrence.

The NRMP has fully adopted this tool for operational use, and it has helped rabies managers optimize data collection and allocate resources for surveillance efforts. In addition, the NRMP, NWRC, and Canadian partners are using the new method in several collaborative studies to enhance raccoon rabies management.

- **NWRC Employee of the Year Awards.** The winners of this award are nominated by their peers as employees who have clearly exceeded expectations in their contributions toward the NWRC mission. The winners this year are:
  - Dr. Amy Gilbert, Research Grade Scientist; Methods and Strategies for Controlling Rabies Project; Fort Collins, CO
  - Doreen Griffin, Support Scientist; Chemistry Unit; Fort Collins, CO
  - Sean Lamb, Technician; Animal Care Unit; Fort Collins, CO
  - Mary Kimball, Budget Analyst; Administration Unit; Philadelphia, PA
- **APHIS Administrator's Award.** In FY 2020, WS NWRC researcher Bryan Kluever, along with WS Operations employees John McConnell, Brett Dunlap, Andrew Montoney, and Kimberly Clapper, received an APHIS Administrator's Award for their extraordinary efforts and collaboration to assist livestock producers with threats and damages caused by black vultures and for continued efforts to expand both operational and research endeavors to further the understanding of black vulture populations and ecology as it relates to wildlife damage management.
- **APHIS Scientist of the Year Award.** Researchers from the NWRC Feral Swine Project were one of four finalists for the FY 2020 APHIS Scientist of the Year Award for their contributions to *Invasive Wild Pigs: Ecology, Impacts and Management*, a comprehensive, 480-page reference book on invasive feral swine. Nominees were judged on the following criteria: scientific impact, scientific collaborative spirit, fostering an exceptional scientific work environment, supporting science in APHIS' mission, and external scientific recognition. The book was also named The Wildlife Society's 2020 Wildlife Publication of the Year in the Edited Book Category.

2020 Publications

The transfer of scientific information is an important part of the research process. NWRC scientists publish in a variety of peer-reviewed journals that cover a wide range of disciplines, including wildlife management, genetics, analytical chemistry, ornithology, and ecology. (Note: 2019 publications that were not included in the 2019 NWRC accomplishments report are listed here.)

Baldwin, R.A., D.I. Stetson, M.G. Lopez, and R.M. Engeman. 2019. An assessment of vegetation management practices and burrow fumigation with aluminum phosphide as tools for managing voles within perennial crop fields in California, USA. Environmental Science and Pollution Research 26(18):18434-18439. doi: 10.1007/s11356-019-05235-6

Banyard, A.C., A. Davis, A.T. Gilbert, W. Markotter. 2020. Bat rabies. pgs 231-276. In: Fooks, A.R. and Jackson, A.C. editors. Rabies: Scientific basis of the disease and its management. Academic Press.

Barela, I., L.M. Burger, J. Taylor, K.O. Evans, R. Ogawa, L. McClintic, and G. Wong. 2020. Relationships between survival and habitat suitability of semi-aquatic mammals. Ecology and Evolution 10(11):4867-4875. doi: 10.1002/ece3.6239

Barton, K.E., C. Jones, K.F. Edwards, A.B. Shiels, and T. Knight. 2020. Local adaptation constrains drought tolerance in a tropical foundation tree. Journal of Ecology 108(4):1540-1552. doi: 10.1111/1365-2745.13354

Beasley, J.C., M.J. Lavelle, D.A. Keiter, K.M. Pepin, A.J. Piaggio, J.C. Kilgo, and K.C. VerCauteren. 2020. Research methods for wild pigs. pgs 199-227. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Beffre, S.J., and B.E. Washburn. 2020. Talking trash in the Big Apple: mitigating bird strikes near the North Shore Marine Transfer Station. Human-Wildlife Interactions 14(1):55-63. doi: 10.26077/pr0z-sf91

Berentsen, A., C. Ellis, S. Johnson, I. Leinbach, R. Sugihara, and A. Gilbert. 2020. Immunogenicity of Ontario rabies vaccine for small Indian mongooses (*Herpestes auropunctatus*). Journal of Wildlife Diseases 56(1):224-228. doi: 10.7589/2019-03-074

Berentsen, A.R., F.B. Torres-Toledo, A.J. Davis, A.T. Gilbert, and M.J. Rivera-Rodriguez. 2020. Flavor preference of oral rabies vaccine baits by small Indian mongooses (*Herpestes auropunctatus*) in southwestern Puerto Rico. Proceedings of the Vertebrate Pest Conference 29. Paper no. 10. 5 pp.

Berentsen, A.R., L. Cruz-Martinez, A. Vos, S. Ortmann, A. Kretzschmar, C. Kaiser, L. Herve-Claude, D. Knobel, and C.E. Rupprecht. 2020. Disappearance rates of a placebo bait for the small Indian mongoose across different habitats on St. Kitts. Caribbean Journal of Science 50(2):236-241. doi: 10.18475/cjos.v50i2.a5

Berentsen, A.R., M.J. Rivera-Rodriguez, K.M. McClure, F.B. Torres-Toledo, J.G. Garcia-Cancel, and A.T. Gilbert. 2020. Home range estimates for small Indian mongooses (*Urva auropunctata*) in southwestern Puerto Rico. Caribbean Journal of Science 50(2):225-235. doi: 10.18475/cjos.v50i2.a4

Berentsen, A.R., R.B. Chipman, K.M. Nelson, K.S. Gruver, F. Boyd, S.F. Volker, A.J. Davis, A. Vos, S. Ortmann, and A.T. Gilbert. 2019. Placebo oral rabies vaccine bait uptake by small Indian mongooses (*Herpestes auropunctatus*) in southwestern Puerto Rico. Journal of Wildlife Diseases 56(2):452-456. doi: 10.7589/2019-03-077

Blackwell, B.F., T.W. Seamans, M.B. Pfeiffer, and B.N. Buckingham. 2020. Predator scent and visual cue applied to nest boxes fail to dissuade European starlings (*Sturnus vulgaris*) from nesting. The Wilson Journal of Ornithology 132(1):113-123. doi: 10.1676/1559-4491-132.1.113

Blackwell, B.F., T.W. Seamans, T.L. DeVault, S.L. Lima, M.B. Pfeiffer, and E. Fernandez-Juricic. 2019. Social information affects Canada goose alert and escape responses to vehicle approach: implications for animal-vehicle collisions. PeerJ 7:e8164. doi: 10.7717/peerj.8164

Bogardus, T., S.M. Joe, and A.B. Shiels. 2020. Development of a rodent bait with slug-repellent properties. Proceedings of the Vertebrate Pest Conference 29. Paper no. 14. 3 pp.

Boyce, C.M., K.C. VerCauteren, and J.C. Beasley. 2020. Timing and extent of crop damage by wild pigs (*Sus scrofa Linnaeus*) to corn and peanut fields. Crop Protection 133:15131. doi: 10.1016/j.cropro.2020.105131

Brook, R.K. and M.P. Glow. 2020. Wild pigs in north-central North America. pgs 305-317. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Brown, V.R., M.C. Marlow, T. Gidlewski, R. Bowen, and A. Bosco-Lauth. 2020. Perspectives on the past, present, and future of feral swine disease surveillance in the United States. Journal of Animal Science 98(8):skaa256. doi: 10.1093/jas/skaa256

Burr, P.C., J.L. Avery, G.M. Street, B.K. Strickland, and B.S. Dorr. 2020. Fine scale characteristics of catfish aquaculture ponds influencing piscivorous avian species foraging use in the Mississippi Delta. PLoS ONE 15(2):e0229402. doi: 10.1371/journal.pone.0229402

Burr, P., J. Avery, G. Street, B. Strickland, and B. Dorr. 2020. Fish-eating birds on catfish ponds in the Mississippi Delta. Mississippi State University Extension Service Publication 3482. Mississippi State University. Starkville, Mississippi. 8 pp.

Carlson, J.C., J.C. Chandler, B. Bisha, J.T. LeJeune, and T.E. Wittum. 2020. Bird-livestock interactions associated with increased cattle fecal shedding of ciprofloxacin-resistant *Escherichia coli* within feedlots in the United States. Scientific Reports 10:10174. doi: 10.1038/s41598-020-66782-4

Carpenter, J.K., J.M. Wilmshurst, K.R. McConkey, J.P. Hume, D.M. Wotton, A.B. Shiels, O.R. Burge, and D.R. Drake. 2020. The forgotten fauna: native vertebrate seed predators on islands. Functional Ecology 34(9):1802-1813. doi: 10.1111/1365-2435.13629

Chandler, J.C., A.B. Franklin, S.N. Bevins, K.T. Bentler, J. Bonnedahl, C.A. Ahlstrom, B. Bisha, and S.A. Shriner. 2020. Validation of a screening method for the detection of colistin-resistant *E. coli* containing *mcr-1* in feral swine feces. Journal of Microbiological Methods 172:105892. doi: 10.1016/j.mimet.2020.105892

Chandler, J.C., J.E. Anders, N.A. Blouin, J.C. Carlson, J.T. LeJeune, L.D. Goodridge, B. Wang, L.A. Day, A.M. Mangan, D.A. Reid, S.M. Coleman, M.W. Hopken, and B. Bisha. 2020. The role of European starlings (*Sturnus vulgaris*) in the dissemination of multidrug-resistant *Escherichia coli* among concentrated animal feeding operations. Scientific Reports 10:8093. doi: /10.1038/s41598-020-64544-w

Choi, D.Y., T.W. Wittig, and B.M. Kluever. 2020. An evaluation of bird and bat mortality at wind turbines in the Northeasterm United States. PLoS ONE 15(8):e0238034. doi: 10.1371/journal.pone.0238034

Christie, T., B. Dorr, L. Roy, A.M. Kelly, C. Engle, P. Burr, B. Davis, and J. van Senten. 2020. Cormorant predation of commercial catfish aquaculture in the Mississippi Delta. AAEC-231. Virginia Cooperative Extension, Virginia Tech. Blacksburg, Virginia. 4 p.

Clements, S.A., B.S. Dorr, J.B. Davis, L.A. Roy, C.R. Engle, K.C. Hanson-Dorr, and A.M. Kelly. 2020. Diets of scaup occupying baitfish and sportfish farms in eastern Arkansas. Food Webs 23:e00141. doi: 10.1016/j.fooweb.2020.e00141

Cox, R.J., P. Nol, C.K. Ellis, and M.V. Palmer. 2019. Research with agricultural animals and wildlife. ILAR Journal 60(1):66-73. doi: 10.1093/ilar/ilz006

Cunningham, F.L., K.C. Hanson-Dorr, L. Ford, D.R. Middleton, A. Crain, L. Durst, C. Ware, M.J. Griffin, C.C. Mischke, X.-F. Wan, and L.A. Hanson. 2019. Environmental factor(s) and animal vector(s) associated with atypical *Aeromonas hydrophila* abundance and dissemination among channel catfish ponds. Journal of the World Aquaculture Society 2019:1-13. doi: 10.1111/jwas.12608

Dannemiller, N.G., K.E. Horak, J.W. Ellis, N.L. Barrett, L.L. Wolfe, and S.A. Shriner. 2019. Effects of external oiling and rehabilitation on hematological, biochemical, and blood gas analytes in ring-billed gulls (*Larus delawarensis*). Frontiers in Veterinary Science 6:405. doi: 10.3389/fvets.2019.00405

Davis, A.J., D.A. Keiter, E.M. Kierepka, C. Slootmaker, A.J. Piaggio, J.C. Beasley, and K.M. Pepin. 2020. A comparison of cost and quality of three methods for estimating density for wild pigs (*Sus scrofa*). Scientific Reports 10:2047. doi: 10.1038/s41598-020-58937-0

Davis, A.J., J.D. Kirby, R.B. Chipman, K.M. Nelson, T. Xifara, C.T. Webb, R. Wallace, A.T. Gilbert, and K.M. Pepin. 2019. Not all surveillance data are created equal - a multi-method dynamic occupancy approach to determine rabies elimination from wildlife. Journal of Applied Ecology 56(11):2551-2561. doi: 10.1111/1365-2664.13477

Davis, A.J., K.M. Nelson, J.D. Kirby, R. Wallace, X. Ma, K.M. Pepin, R.B. Chipman, and A.T. Gilbert. 2019. Rabies surveillance identifies potential risk corridors and enables management evaluation. Viruses 11(11):1006. doi: 10.3390/v11111006

DeVault, T.L., T.W. Seamans, and B.F. Blackwell. 2020. Frontal vehicle illumination via rear-facing lighting reduces potential for collisions with white-tailed deer. Ecosphere 11(7):e03187. doi: 10.1002/ecs2.3187

Ditchkoff, S.S., J.C. Beasley, J.J. Mayer, G.J. Roloff, B.K. Strickland, and K.C. VerCauteren. 2020. The future of wild pigs in North America. pgs 465-469. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Dorr, B.S., P.D. Mathewson, K.C. Hanson-Dorr, K.A. Healy, K.E. Horak, and W. Porter. 2020. Landscape scale thermoregulatory costs from sublethal exposure to Deep Water Horizon oil in the double-crested cormorant. Marine Pollution Bulletin 152:110915. doi: 10.1016/j.marpolbul.2020.110915

Ellingwood, D.D., P.J. Pekins, H. Jones, and A.R. Musante. 2020. Evaluating moose (*Alces alces*) population response to infestation level of winter ticks (*Dermacentor albipictus*). Wildlife Biology 2020(2):wlb.00619. doi: 10.2981/wlb.00619.

Engeman, R.M., B.W. Kaiser, and K.J. Osorio. 2019. Evaluating methods to detect and monitor populations of a large invasive lizard: the Argentine giant tegu. Environmental Science and Pollution Research 26(31):31717-31729. doi: 10.1007/s11356-019-06324-2

Fischer, J.W., N.P. Snow, B.E. Wilson, S.F. Beckerman, C.N. Jaques, E.H. VanNatta, S.L. Kay, and K.C. VerCauteren. 2020. Factors and costs associated with removal of a newly established population of invasive wild pigs in Northern U.S. Scientific Reports 10:11528. doi: 10.1038/s41598-020-68264-z

Flies, A.S., E.J. Flies, S. Fox, A. Gilbert, S.R. Johnson, G.-S. Liu, A.B. Lyons, A.L. Patchett, D. Pemberton, and R.J. Pye. 2020. An oral bait vaccination approach for the Tasmanian devil facial tumor diseases. Expert Review of Vaccines 19(1):1-10. doi: 10.1080/14760584.2020.1711058

Franklin, A.B., A.M. Ramey, K.T. Bentler, N.L. Barrett, L.M. McCurdy, C.A. Ahlstrom, J. Bonnedahl, S.A. Shriner, and J.C. Chandler. 2020. Gulls as sources of environmental contamination by colistin-resistant bacteria. Scientific Reports 10:4408. doi: 10.1038/s41598-020-61318-2

Franklin, A.B. and S.N. Bevins. 2020. Spillover of SARS-CoV-2 into novel wild hosts in North America: a conceptual model for perpetuation of the pathogen. Science of the Total Environment 733:139358. doi: 10.1016/j.scitotenv.2020.139358

Friebohle, J., S.R. Siers, and C.E. Montgomery. 2020. Acetaminophen as an oral toxicant for invasive California kingsnakes (*Lampropeltis californiae*) on Gran Canaria, Canary Islands, Spain. Management of Biological Invasions 11(1):122-138.

Gifford, S.J., E.M. Gese, and R.R. Parmenter. 2020. Food habits of coyotes (*Canis latrans*) in the Valles Caldera National Preserve, New Mexico. The Southwestern Naturalist 64(2):122-130. doi: 10.1894/0038-4909-64-2-122

Gigliotti, L.C., N.D. Berg, R. Boonstra, S.M. Cleveland, D.R. Diefenbach, E.M. Gese, J.S. Ivan, K. Kielland, C.J. Krebs, A.V. Kumar, L.S. Mills, J.N. Pauli, H.B. Underwood, E.C. Wilson, and M.J. Sheriff. 2020. Latitudinal variation in snowshoe hare (*Lepus americanus*) body mass: a test of Bergmann's rule. Canadian Journal of Zoology 98:88-95. doi: 10.1139/cjz-2019-0184

Gilbert, A.T. and R.B. Chipman. 2020. Rabies control in wild carnivores. pgs 605-654. In: Fooks, A.R. and A.C. Jackson, editors. Rabies: Scientific Basis of the Disease and Its Management. Academic Press.

Gilbert, A.T., X. Wu, F.R. Jackson, R. Franka, G.F. McCracken, and C.E. Rupprecht. 2020. Safety, immunogenicity, and efficacy of intramuscular and oral delivery of ERA-G333 recombinant rabies virus in big brown bats (*Eptesicus fuscus*). Journal of Wildlife Diseases 56(3):620-630. doi: 10.7589/2019-04-108

Glow, M.P., J.J. Mayer, B.A. Friesenhahn, and K.C. VerCauteren. 2020. Wild pigs in western North America. pgs 275-303. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Godwin, J., M. Serr, S.K. Barnhill-Dilling, D.V. Blondel, P.R. Brown, K. Campbell, J. Delborne, A.L. Lloyd, K.P. Oh, T.A.A. Prowse, R. Saah, and P. Thomas. 2019. Rodent gene drives for conservation: opportunities and data needs. Proceedings of the Royal Society B Biological Sciences 286(1914):20191606. doi: 10.1098/rspb.2019.1606

Goetz, S.M., A.A. Yackel Adams, and S.R. Siers. 2020. Validating deployment of aerially delivered toxic bait cartridges for control of invasive brown tree snakes. Wildlife Society Bulletin 44(3):617-622. doi: 10.1002/wsb.1106

Gray, S.M., G.J. Roloff, R.A. Montgomery, J.C. Beasley, and K.M. Pepin. 2020. Wild pig spatial ecology and behavior. pgs 33-56. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Gray, S.M., G.J. Roloff, D.B. Kramier, D.R. Etter, K.C. VerCauteren, and R.A. Montgomery. 2020. Effects of wild pig disturbance on forest vegetation and soils. The Journal of Wildlife Management 84(4):739-748. doi: 10.1002/jwmg.21845

Guan, X., E.R. Britzke, A.J. Piaggio, D.L. Bergman, L. Van Pelt, and R.F. Lance. 2020. Genetic assays for guano-based identification of species and sex in bats of the United States and Guam. Journal of Mammalogy 101(4):970–978. doi: 10.1093/jmammal/gyaa059

Gutierrez, RJ, G. Jones, S.M. Redpath, A.B. Franklin, D. Simberloff, M.G. Turner, V.C. Radeloff, G.C. White, and M.Z. Peery. 2019. Reinforcing the concept of agenda-driven science: a response to Rohlf. Frontiers in Ecology and the Environment 17(10):556-557. doi: 10.1002/fee.2131

Hill, J.E., T.L. DeVault, and J.L. Belant. 2019. Impact of the human footprint on anthropogenic mortality of North American reptiles. Acta Oecologica 101:103486. doi: 10.1016/j.actao.2019.103486

Hill, J.E., T.L. DeVault, and J.L. Belant. 2020. Protected areas reduce poaching but not overall anthropogenic mortality of North American mammals. Global Ecology and Conservation 21:e00810. doi: 10.1016/j.gecco.2019.e00810

Hill, J.E., T.L. DeVault, and J.L. Belant. 2019. CauseSpec: a database of global terrestrial vertebrate cause-specific mortality. Ecology 100(12):e02865. doi: 10.1002/ecy.2865

Holland, A.E., M.E. Byrne, J. Hepinstall-Cymerman, A.L. Bryan, T.L. DeVault, O.E. Rhodes, Jr., and J.C. Beasley. 2019. Evidence of niche differentiation for two sympatric vulture species in the Southeastern United States. Movement Ecology 7:31. doi: 10.1186/s40462-019-0179-z

Hopken, M.W., A.J. Piaggio, K.L. Pabilonia, J. Pierce, T. Anderson, and Z. Abdo. 2020. Predicting whole genome sequencing success for archived avian influenza virus (Orthomyxoviridae) samples using real-time and droplet PCRs. Journal of Virological Methods 276: 113777. doi: 10.1016/j.jviromet.2019.113777

Horak, K.E., N.L. Barrett, J.W. Ellis, E.M. Campbell, N.G. Dannemiller, and S.A. Shriner. 2020. Effects of Deepwater Horizon oil on feather structure and thermoregulation in gulls: does rehabilitation work? Science of the Total Environment 718:137380. doi: 10.1016/j.scitotenv.2020.137380

Horak, K.E., C.M. Campton, and S.F. Volker. 2020. Are reports of reduced field efficacy of diphacinone and chlorophacinone in California ground squirrels (*Otospermophilus beecheyi*) due to elevated rodenticide metabolism? Crop Protection 127:104969 doi: 10.1016/j.cropro.2019.104969

Hudson, S.B., B.M. Kluever, A.C. Webb, and S.S. French. 2020. Steroid hormones, energetic state, and immunocompetence vary across reproductive contexts in a parthenogenetic lizard. General and Comparative Endocrinology 288:113372. doi: 10.1016/j.ygcen.2019.113372

Johnson, H.E., D.L. Lewis, and S.W. Breck. 2020. Individual and population fitness consequences associated with large carnivore use of residential development. Ecosphere 11(5):e03098. doi: 10.1002/ecs2.3098

Kinka, D. and J.K. Young. 2019. Evaluating domestic sheep survival with different breeds of livestock guardian dogs. Rangeland Ecology & Management 72(6):923-932. doi: 10.1016/j.rama.2019.07.002

Kimble, S.J.A., B.S. Dorr, K.C. Hanson-Dorr, O.E. Rhodes, Jr., and T.L. DeVault. 2020. Migratory flyways may affect population structure in double-crested cormorants. The Journal of Wildlife Management 84(5):948-956. doi: 10.1002/jwmg.21848

Klymus, K.E., C.M. Merkes, M.J. Allison, C.S. Goldberg, C.C. Helbing, M.E. Hunter, C.A. Jackson, R.F. Lance, A.M. Mangan, E.M. Monroe, A.J. Piaggio, J.P. Stokdyk, C.C. Wilson, and C.A. Richter. 2020. Reporting the limits of detection and quantification for environmental DNA assays. Environmental DNA 2(3):271-282. doi: 10.1002/edn3.29

Kraus, F., R. Sugihara, and S. Siers. 2020. Testing toxicants and baits to control small invasive lizards. Management of Biological Invasions 11(3):461-475. doi: 10.3391/mbi.2020.11.3.08

Lewis, J.S., K.C. VerCauteren, R.M. Denkhaus, and J.J. Mayer. 2020. Wild pig populations along the urban gradient. pgs 439-463. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Lillie, K.M., E.M. Gese, T.C. Atwood, and M.M. Conner. 2019. Use of subsistence-harvested whale carcasses by polar bears in the Southern Beaufort Sea. Arctic 74(4):337-484. doi: 10.14430/arctic69449

Maurer, D.L., C.K. Ellis, T.C. Thacker, S. Rice, J.A. Koziel, P. Nol, and K.C. VerCauteren. 2019. Screening of microbial volatile organic compounds for detection of disease in cattle: development of lab-scale method. Scientific Reports 9:12103. doi: 10.1038/s41598-019-47907-w

Martens, F.R., M.B. Pfeiffer, C.T. Downs, and J.A. Venter. 2020. Cliff roost site selection of the endangered Cape vulture *Gyps coprotheres* in the Eastern Cape province, South Africa. Ostrich 91(1):25-34. doi: 10.2989/00306525.2019.1651417

Massei, G., D. Cowan, D. Eckery, R. Mauldin, M. Gomm, P. Rochaix, F. Hill, R. Pinkham, and L.A. Miller. 2020. Effect of vaccination with a novel GnRH-based immunocontraceptive on immune responses and fertility in rats. Heliyon 6(4):e03781. doi: 10.1016/j.heliyon.2020.e03781

Mathies, T., and R.E. Mauldin. 2020. Lethal methemoglobinemia in the invasive brown tree snake after acetaminophen ingestion. Scientific Reports 10(1):845. doi: 10.1038/s41598-019-56216-1

Mauldin, R.E., G.W. Witmer, S.A. Shriner, R.S. Moulton, and K.E. Horak. 2020. Effects of brodifacoum and diphacinone exposure on four species of reptiles: tissue residue levels and survivorship. Pest Management Science 76(5):1958-1966. doi: 10.1002/ps.5730

Mayer, J.J., T.J. Smyser, A.J. Piaggio, and S.M. Zervanos. 2020. Wild pig taxonomy, morphology, genetics, and physiology. pgs 7-31. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

McClure, K.M., A.T. Gilbert, R.B. Chipman, E.E. Rees, and K.M. Pepin. 2020. Variation in host home range size decreases rabies vaccination effectiveness by increasing the spatial spread of rabies virus. Journal of Animal Ecology 89(6):1375-1386. doi: 10.1111/1365-2656.13176

McKee, S., A. Anderson, K. Carlisle, and S.A. Shwiff. 2020. Economic estimates of invasive wild pig damage to crops in 12 US states. Crop Protection 132:105105. doi: 10.1016/j.cropro.2020.105105

McRae, J.E., P.E. Schlichting, N.P. Snow, A.J. Davis, K.C. VerCauteren, J.C. Kilgo, D.A. Keiter, J.C. Beasley, and K.M. Pepin. 2020. Factors affecting bait site visitation: area influence of baits. Wildlife Society Bulletin 44(2):362-371. doi: 10.1002/wsb.1074

Nafus, M.G., A.A. Yackel Adams, S.M. Boback, S.R. Siers, and R.N. Reed. 2020. Behavior, size, and body condition predict susceptibility to management and reflect post-treatment frequency shifts in an invasive snake. Global Ecology and Conservation 21:e00834. doi: 10.1016/j.gecco.2019.e00834

Navin, J., S. Weiler, and A. Anderson. 2020. Wildlife strike cost revelation in the US domestic airline industry. Transportation Research Part D: Transport and Environment 78:102204. doi: 10.1016/j.trd.2019.102204

Niebuhr, C.N., S.I. Jarvi, L. Kaluna, B.L. Torres Fischer, A.R. Deane, I.L. Leinbach, and S.R. Siers. 2020. Occurance of rat lungworm (*Angiostrongylus cantonensis*) in invasive coqui frogs (*Eleutherodactylus coqui*) and other hosts in Hawaii. Journal of Wildlife Diseases 56(1):203-207. doi: 10.7589/2018-12-294

Niemiec, R., R.E.W. Berl, M. Gonzalez, T. Teel, C. Camara, M. Collins, J. Salerno, K. Crooks, C. Schultz, S. Breck, and D. Hoag. 2020. Public perspectives and media reporting of wolf reintroduction in Colorado. PeerJ 8:e9074. doi: 10.7717/peerj.9074

Nol, P., M.E. Wehtje, R.A. Bowen, S. Robbe-Austerman, T.C. Thacker, K. Lantz, J.C. Rhyan, L.A. Baeten, R.A. Juste, I.A. Sevilla, C. Gortazar, and J. Vicente. 2020. Effects of inactivated *Mycobacterium bovis* vaccination on Molokai-origin wild pigs experimentally infected with virulent *M. bovis*. Pathogens 9:199. doi: 10.3390/pathogens9030199

Olival, K.J., P.M. Cryan, B.R. Amman, R.S. Baric, D.S. Blehrt, C.E. Brook, C.H. Calisher, K.T. Castle, J.T.H. Coleman, P. Daszak, J.H. Epstein, H. Field, W.F. Frick, A.T. Gilbert, D.T.S. Hayman, H.S. Ip, W.B. Karesh, C.K. Johnson, R.C. Kadling, T. Kingston, J.M. Lorch, I.H. Mendenhall, A.J. Peel, K.L. Phelps, R.K. Plowright, D.M. Reeder, J.D. Reichard, J.M. Sleeman, D.G. Streicker, J.S. Towner, and L.F. Wang. 2020. Possibility for reverse zoonotic transmission of SARS-CoV-2 to free-ranging wildlife: a case study of bats. PLoS Pathogens 16(9):e1008758. doi: 10.1371/journal.ppat.1008758

Pepin, K.M., A.J. Golnar, Z. Abdo, and T. Podgorski. 2020. Ecological drivers of African swine fever virus persistence in wild boar populations: insight for control. Ecology and Evolution 10(6):2846-2859. doi: 10.1002/ece3.6100

Pepin, K.M., N.P. Snow, and K.C. VerCauteren. 2020. Optimal bait density for delivery of acute toxicants to vertebrate pests. Journal of Pest Science 93:723-735. doi: 10.1007/s10340-020-01196-9

Pepin, K.M., T.J. Smyser, A.J. Davis, R.S. Miller, S. McKee, K.C. VerCauteren, W. Kendall, and C. Slootmaker. 2020. Optimal spatial prioritization of control resources for elimination of invasive species under demographic uncertainty. Ecological Applications 30(6):e02126. doi: 10.1002/eap.2126

Perjchar, L., C.A. Lepczyk, J.E. Fantle-Lepczyk, S.C. Hess, M.T. Johnson, C.R. Leopold, M. Marchetti, K.M. McClure, and A.B. Shiels. 2020. Hawaii as a microcosm: advancing the science and practice of managing introduced and invasive species. BioScience 70(2):184-193. doi: 10.1093/biosci/biz154

Pfeiffer, M.B., R.B. Iglay, T.W. Seamans, B.F. Blackwell, and T.L. DeVault. 2020. Deciphering interactions between white-tailed deer and approaching vehicles. Transportation Research Part D: Transport and Environment 79:102251. doi: 10.1016/j.trd.2020.102251

Pfeiffer, M.B., B.F. Blackwell, and T.L. DeVault. 2020. Collective effect of landfills and landscape composition on bird-aircraft collisions. Human-Wildlife Interactions 14(1):43-54. doi: 10.26077/rcfe-z054

Pieracci, E.G., J.A. Brown, D.L. Bergman, A.T. Gilbert, R.M. Wallace, J.D. Blanton, A. Velasco-Villa, C.N. Morgan, S. Lindquist, and R.B. Chipman. 2020. Evaluation of species identification and rabies virus characterization among bat rabies cases in the United States. Journal of the American Veterinary Medical Association 256(1):77-84. doi: 10.2460/javma.256.1.77

Rattner, B.A., S.F. Volker, J.S. Lankton, T.G. Bean, R.S. Lazarus, and K.E. Horak. 2020. Brodifacoum toxicity in American kestrels (*Falco sparverius*) with evidence of increased hazard upon subsequent anticoagulant rodenticide exposure. Environmental Toxicology and Chemistry 39(2):468-481. doi: 10.1002/etc.4629

Rhyan, J., M. McCollum, T. Gidlewski, M. Shalev, G. Ward, B. Donahue, J. Arzt, C. Stenfeldt, F. Mohamed, P. Nol, M. Deng, S. Metwally, and M. Salman. 2020. Foot-and-mouth disease in experimentally infected mule deer (*Odocoileus hemionus*). Journal of Wildlife Diseases 56(1):93-104. doi: 10.7589/2019-03-059

Richard, S.A., I.M.G. Bukovich, E.A. Tillman, S. Jayamohan, J.S. Humphrey, P.E. Carrington, W.E. Bruce, B.M. Kluever, M.L. Avery, and M.R. Parker. 2020. Conspecific chemical cues facilitate mate trailing by invasive Argentine black and white tegus. PLoS ONE 15(8):e0236660. doi: 10.1371/journal.pone.0236660

Root, J.J., J.W. Ellis, and S.A. Shriner. 2020. Effects of freshwater crayfish on influenza A virus persistence in water. Zoonoses and Public Health 67(3):300-307. doi: 10.1111/zph.12688

Root, J.J., and S.A. Shriner. 2020. Influenza A viruses in peridomestic mammals. pgs 415-427. In: Spackman, E., editor. Animal influenza virus: Methods and protocols. Methods in molecular biology, vol. 2123. Humana, New York, New York. doi: 10.1007/978-1-0716-0346-8_32

Rosser, T.G., E.T. Woodyard, M.N. Mychajlonka, D.T. King, M.J. Griffin, M.A. Gunn, and A. Lopez-Porras. 2020. *Ithyoclinostomum yamagutii* n. sp. (Digenea: Clinostomidae) in the great blue heron *Ardea herodias* L. (Aves: Ardeidae) from Mississippi, USA. Systematic Parasitology 97(1):69-82. doi: 10.1007/s11230-019-09892-6

Sanders, H.N., D.G. Hewitt, H.L. Perotto-Baldivieso, K.C. VerCauteren, and N.P. Snow. 2020. Opportunistic predation of wild turkey nests by wild pigs. The Journal of Wildlife Management 84(2):293-300. doi: 10.1002/jwmg.21797

Sanders, H.N., D.G. Hewitt, H.L. Perotto-Baldivieso, K.C. VerCauteren, and N.P. Snow. 2020. Invasive wild pigs as primary nest predators for wild turkeys. Scientific Reports 10:2625. doi: 10.1038/s41598-020-59543-w

Schlichting, P.E., J.C. Beasley, and K.C. VerCauteren. 2020. The naturalized niche of wild pigs in North America. pgs 127-141. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Schlichting, P.E., J.C. Beasley, R.K. Boughton, A.J. Davis, K.M. Pepin, M.P. Glow, N.P. Snow, R.S. Miller, K.C. VerCauteren, and J.S. Lewis. 2020. A rapid population assessment method for wild pigs using baited cameras at 3 study sites. Wildlife Society Bulletin 44(2):372-382. doi: 10.1002/wsb.1075

Sheffels, T.R., M.D. Sytsma, J. Carter, and J.D. Taylor. 2019. Comparing live-capture methods for nutria: single versus multiple-capture cage traps. Human-Wildlife Interactions 13(3):394-399.

Shiels, A.B., C.D. Lombard, L. Shiels, and Z. Hillis-Starr. 2020. Invasive rat establishment and changes in small mammal populations on Caribbean Islands following two hurricanes. Global Ecology and Conservation 22:e00986. doi: 10.1016/j.gecco.2020.e00986

Shiels, A.B., M. Khalsa, D.L. Griffin, C.K. Chow, P. Baiao, S.S. Mann, and A.J. Piaggio. 2020. Cattle egrets regurgitate house mouse carcasses onto a mouse-free island: implications for rodent eradications. Wildlife Research 47(5):436-440. doi: 10.1071/WR19239

Shiels, A.B. and N.P. Kalodimos. 2019. Biology and impacts of Pacific island invasive species. 15. *Psittacula krameri*, the rose-winged parakeet (Psittaciformes: Psittacidae). Pacific Science 73(4):421-449. doi: 10.2984/73.4.1

Shwiff, S., A. Pelham, W. Haden-Chomphosy, V.R. Brown, K. Ernst, and A. Anderson. 2020. Framework for assessing vertebrate invasive species damage: the case of feral swine in the United States. Biological Invasions 22(10):3101–3117. doi: 10.1007/s10530-020-02311-8

Siers, S.R., A.B. Shiels, C.G. Payne, F.M. Chlarson, C.S. Clark, and S.M. Mosher. 2019. Photographic validation of target versus nontarget take of brown tree snake baits. Wildlife Society Bulletin 43(4):752-759. doi: 10.1002/wsb.1023

Siers, S.R., A.B. Shiels, and P.D. Barnhart. 2020. Invasive snake activity before and after automated aerial baiting. The Journal of Wildlife Management 84(2):256-267. doi: 10.1002/jwmg.21794

Siers, S.R., A.B. Shiels, S.F. Volker, K. Rex, and W.C. Pitt. 2020. Brodifacoum residues in fish three years after an island-wide rat eradication attempt in the tropical Pacific. Management of Biological Invasions 11(1):105-121.

Slate, D., B.D. Saidy, A. Simmons, K.M. Nelson, A. Davis, T.P. Algeo, S.A. Elmore, and R.B. Chipman. 2020. Rabies management implications based on raccoon population density indexes. The Journal of Wildlife Management 84(5):877-890. doi: 10.1002/jwmg.21869

Smyser, T.J., M.A. Tabak, C. Slootmaker, M.S. Roeson, II, R.S. Miller, M. Bosse, H.J. Megens, M.A.M. Groenen, S.R. Paiva, D. Assis de Faria, H.D. Blackburn, B.S. Schmit, and A.J. Piaggio. 2020. Mixed ancestry from wild and domestic lineages contribute to the rapid expansion of invasive feral swine. Molecular Ecology 29(6):1103-1119. doi: 10.1111/mec.15392

Snow, N.P., R.S. Miller, J.C. Beasley, and K.M. Pepin. 2020. Wild pig population dynamics. pgs 57-82. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Stahl, R.S., B. Bisha, S. Mahapatra, and J.C. Chandler. 2020. A model for the prediction of antimicrobial resistance in *Escherichia coli* based on a comparative evaluation of fatty acid profiles. Diagnostic Microbiology and Infectious Disease 96(3):114966. doi: 10.1016/j.diagmicrobio.2019.114966

Sudweeks, J., B. Hollingsworth, D.V. Blondel, K.J. Campbell, S. Dhole, J.D. Eisemann, O. Edwards, J. Godwin, G.R. Howald, K.P. Oh, A.J. Piaggio, T.A.A. Prowse, J.V. Ross, J.R. Saah, A.B. Shiels, P.A. Thomas, D.W. Threadgill, M.R. Vella, F. Gould, and A.L. Lloyd. 2019. Locally fixed alleles: a method to localize gene drive to island populations. Scientific Reports 9:15821. doi: 10.1038/s41598-019-51994-0

Teem, J.L., L. Alphey, S. Descamps, M. Edgington, O.R. Edwards, N.J. Gemmell, T. Harvey-Samuel, R. Melnick, K. Oh, A.J. Piaggio, R. Saah, D. Schill, P.Q. Thomas, T. Smith, and A.F. Roberts. 2020. Genetic biocontrol for invasive species. Frontiers in Bioengineering and Biotechnology 8:452. doi: 10.3389/fbioe.2

VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland. 2020. Introduction. pgs 1-5. In: VerCauteren, K.C., J.C. Beasley, S.S. Ditchkoff, J.J. Mayer, G.J. Roloff, and B.K. Strickland, editors. Invasive Wild Pigs in North America: Ecology, Impacts, and Management. CRC Press, Boca Raton, Florida.

Veum, L.M., B.S. Dorr, K.C. Hanson-Dorr, R.J. Moore, and S.A. Rush. 2019. Data of soil, vegetation and bird species found on double-crested cormorant colonies in the Southeastern United States. Data in Brief 27:104726. doi: 10.1016/j.dib.2019.104726

Werner, S.J., J.W. Fischer, and K.A. Hobson. 2020. Multi-isotopic (δ2H, δ13C, δ15N) tracing of molt origin for European starlings associated with U.S. dairies and feedlots. PLoS ONE 15(8):e0237137. doi: 10.1371/journal.pone.0237137

Westerfield, G.D., J.M. Shannon, O.V. Duvuvuei, T.A. Decker, N.P. Snow, E.D. Shank, B.F. Wakeling, and H.B. White. 2019. Methods for managing human-deer conflicts in urban, suburban, and exurban areas. Human-Wildlife Interactions Monograph Number 3:1–99.

Wilber, M.Q., C.T. Webb, F.L. Cunningham, K. Pedersen, X.-F. Wan, and K.M. Pepin. 2020. Inferring seasonal infection risk at population and regional scales from serology samples. Ecology 101(1):e02882. doi: 10.1002/ecy.2882

Wilber, M.Q., S.M. Chinn, J.C. Beasley, R.K. Boughton, R.K. Brook, S.S. Ditchkoff, J.W. Fischer, S.B. Hartley, L.K. Holmstrom, J.C. Kilgo, J.S. Lewis, R.S. Miller, N.P. Snow, K.C. VerCauteren, S.M. Wisely, C.T. Webb, and K.M. Pepin. 2020. Predicting functional responses in agro-ecosystems from animal movement data to improve management of invasive pests. Ecological Applications 30(1):e02015. doi: 10.1002/eap.2015

Witmer, G.W. 2019. Reducing prairie dog populations and damage by castration of dominant males. Proceedings of the Wildlife Damage Management Conference 18:28–31.

Witmer, G.W. 2020. Captive Canada geese acceptability and toxicity trials with two formulations of 0.005% diphacinone rodenticide baits. Proceedings of the Vertebrate Pest Conference 29. Paper no. 5. 5 pp.

Witmer, G.W., N.P. Snow, and R.S. Moulton. 2020. Time allocation to resources by three species of rats (*Rattus* spp.) in a radial arm maze. Wildlife Research 47(1):25–33. doi: 10.1071/WR18165

Young, J.K., S.W. Breck, and E. Hammill. 2019. Interactions with humans shape coyote responses to hazing. Scientific Reports 9:20046. doi: 10.1038/s41598-019-56524-6

Appendix I

List of 2020 NWRC Research Projects

Defining Economic Impacts and Developing Strategies for Reducing Avian Predation in Aquaculture
Project Leader: Fred Cunningham

Developing Control Methods, Evaluating Impacts, and Applying Ecology To Manage Carnivores
Project Leader: Julie Young

Developing Methods To Manage Damage and Disease of Feral Swine and Other Ungulates
Project Leader: Kurt VerCauteren

Development of Injectable and Mucosal Reproductive Technologies and Their Assessment for Wildlife Population and Disease Management
Project Leader: Jason Bruemmer

Economics, Operations Research, and Social Dimensions of Wildlife Management
Project Leader: Stephanie Shwiff

Evaluation and Development of Wildlife Repellents and Repellent Application Strategies
Project Leader: Scott Werner

Genetic Methods To Manage Livestock-Wildlife Interactions
Project Leader: Antoinette Piaggio

Improving Methods To Manage Healthy Forests, Wetlands, and Rangelands
Project Leader: Jimmy Taylor

Methods and Strategies for Controlling Rabies
Project Leader: Amy Gilbert

Methods and Strategies To Manage Invasive Species Impacts to Agriculture, Natural Resources, and Human Health and Safety
Project Leader: Steven Hess

Methods and Strategies To Manage Rodent Impacts to Agriculture, Natural Resources, and Human Health and Safety
Project Leader: Gary Witmer

Methods Development and Damage Management of Depredating Birds and Invasive Wildlife
Project Leader: Bryan Kluever

Methods Development To Reduce Bird Damage to Agriculture: Evaluating Methods at Multiple Biological Levels and Landscape Scales
Project Leader: Page Klug

Understanding and Exploiting Wildlife Behavior To Mitigate Wildlife Collisions With Aircraft, Other Vehicles, and Structures
Project Leaders: Brad Blackwell

Wildlife-Borne Pathogens Affecting Food Safety and Security: Developing Methods To Mitigate Effects
Project Leader: Alan Franklin

Wildlife Disease Dynamics, Epidemiology, and Response
Project Leader: Susan Shriner

More information about these projects is available on the NWRC web page at:
www.aphis.usda.gov/wildlifedamage/nwrc

Appendix 2

NWRC Research Contacts

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Bevins, Sarah	(970) 266-6211 sarah.n.bevins@usda.gov	NWDP: wildlife disease
Blackwell, Bradley	(419) 625-0242 ext. 15 bradley.f.blackwell@usda.gov	Aviation hazards, lighting systems
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Werner, Scott	(970) 266-6136 scott.j.werner@usda.gov	Project Leader: repellents
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Appendix 3

Acronyms and Abbreviations

APHIS	Animal and Plant Health Inspection Service
ASF	African swine fever
β-CoVs	beta-coronaviruses
DFT	devil facial tumor
DNA	deoxyribonucleic acid
eDNA	environmental DNA
EPA	U.S. Environmental Protection Agency
EUP	experimental use permit
FAA	Federal Aviation Administration
GnRH	gonadotropin-releasing hormone
GPS	global positioning system
HISC	Hawaii Invasive Species Committee
IRC	Island Restoration Committee
km	kilometer
LED	light-emitting diode
MAF	*Mycobacterium avium* cell wall fragment
mg	milligram
NASS	National Agricultural Statistics Service
NFSDMP	National Feral Swine Damage Management Program
NRMP	National Rabies Management Program
NWRC	National Wildlife Research Center
OBV	oral bait vaccine
ONRAB	Ontario rabies vaccine bait
ORV	oral rabies vaccine
PCR	polymerase chain reaction
RDI	raccoon density index
RNA	ribonucleic acid
RPA	rapid population assessment
rrt-PCR	real-time reverse transcription polymerase chain reaction
rt-dd PCR	reverse transcription droplet digital polymerase chain reaction
RVNA	rabies virus neutralizing antibody
USDA	U.S. Department of Agriculture
WS	Wildlife Services

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